Journal of
Experimental Psychology

VOL. 29, No. 6 DECEMBER, 1941

A STUDY OF THE EXTINCTION OF UNCONDITIONED REFLEXES[1]

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I. INTRODUCTION

The extinction of a reflex to stimulation repeated at a rate which precludes effector fatigue or sensory adaptation has been observed by investigators in a variety of organisms and responses. Danisch (3), for example, observed it in vorticella, Prosser and Hunter (14) in the normal and spinal rat, Beritoff (1) in the normal and spinal dog, and Coombs (2) in human beings. The phenomenon is believed by many to be similar to that observed in conditioned reactions. Humphrey (8), for instance, believes this type of extinction to represent the simplest form of learning, with conditioning, maze learning, and puzzle-box behavior coming next in order. And Razran, also relating it to conditioned extinction, calls it 'the most general fundamental phenomenon of behavior modifiability' (15, p. 34).

The extent of the similarity between the phenomena observed in conditioned and unconditioned reactions can only be ascertained, however, by careful analysis of each situation. Extensive work has been done on the extinction of conditioned reactions; but relatively little effort has been made to determine under what conditions the extinction of unconditioned reactions occurs, the nature of such extinction, and the kind of reflexes which are subject to such extinction. The present investigation was undertaken to obtain additional information on these points, and it consists of a study of reflexes in several organisms under comparable conditions of stimulation.

Reflexes, particularly from the clinical point of view, may be classified into two groups, (1) the so-called deep or tendon reflexes,

[1] The writer wishes to express his gratitude to Professor Walter S. Hunter, under whose direction this investigation was conducted.

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elicited by a tap stimulus, which are mediated solely through a spinal arc, and (2) the superficial or cutaneous reflexes, elicited by stroking the skin, which have superimposed cortical pathways. The tail reflex of the spinal rat, the patellar reflex of both the spinal and normal cat, and the biceps reflex of the human being were selected as typical deep reflexes. As representative superficial reflexes, the plantar reflex and the abdominal reflex in the human being were investigated. In addition, two other responses were studied, the respiratory startle response in the rat and the pupillary reflex in the human being.

II. Reflexes Showing Extinction

Tail Reflex of the Spinal Rat

Procedure.—The results to be presented were obtained with 4 male and 7 female rats, 4–6 months of age, who were made chronic spinal preparations by transection of the cord at the mid-thoracic level under ether anesthesia. No signs of conduction across the transection were noted. A post-mortem examination of 4 of the animals showed no intact fibers. No extinction records were taken from an animal until at least 24 hours after the operation, and usually a longer period of time elapsed. Since it was necessary in the present experiment that an animal remain quiet throughout each experimental session, an effort was made to select tame animals who were then habituated to the necessary experimental restraint for 30 minutes on each of 4–5 days.

The animal was restrained in a zipper bag which left free its head, hind legs, and tail, and it was tied in a prone position on a specially fitted metal holder whose height could be adjusted to bring the animal into a position corresponding the the height of a small block of wood, to the top of which the rat's tail was fastened with 2 strips of tape 2 cm wide and about 3 cm apart. This held the tail firmly in place and helped insure the application of the stimulus to the same sopt.

The stimulus was applied to the tail between these strips of tape by means of a small metal rod, or tapper, which had a tip 3 mm in diameter. The rod was suspended by a steel spring and was moved through a distance of 2.5 cm by a solenoid connected with a 6-volt battery. A rheostat and ammeter in the circuit made possible the control of the force with which the rod hit the tail. The intensity of the stimulus was slightly above threshold value for the tail reflex and was kept constant for all work. The reflex was recorded kymographically by means of a thread tied to the base of the tail. Stimulation was given automatically every 15 seconds by means of a telechron motor timing device. The onset of the stimulus and its duration (which was about one second) were recorded, simultaneously with the response, on a slowly moving waxed-paper kymograph. The disinhibiting stimulus was a pinch of the tail with a small tweezers applied to the same spot throughout an experimental session. The pressure with which the tweezers were applied was roughly controlled and kept as nearly constant as possible.

In an experimental session the tail reflex was elicited every 15 seconds until it failed to appear to 3 successive stimulations. Fifteen seconds after the third failure to respond, the disinhibiting stimulus was applied. Fifteen seconds later the regular series of tap-stimulations was again resumed. This procedure was repeated for successive extinctions until the disinhibiting stimulus was no longer effective in restoring the response to the regular stimulus.

This extinction series constituted the experimental session for the day. An attempt was made to obtain such a series each day from each animal. This was not always possible, however, because if in an experimental session the animal moved, or in some other way was disinhibited, the data were not used. Only complete extinction series enter into the results here reported.

Results.—Extinction will be described first in terms of the number of stimulations required and then in terms of the decreased magnitude of response. Twenty-one extinction series of the tail reflex were obtained from the 11 animals. The summary of these data is pre-

TABLE I

NUMBER OF STIMULATIONS PER EXTINCTION OF THE TAIL REFLEX IN THE SPINAL RAT

No. of Extinctions	Subjects																						Total Ext.	Total Stim.	Av. No. Stim.
	1	2			1-L	2-LR		4	5		6		7			3		8			2-N				
1	9	18	19	16	6	23	10	14	8	7	8	8	14	19	8	12	17	16	16	11	8		21	267	12.71
2	7	10	16	7	4	15	7	5	3	5	4	8	6	13	8	5	6	7	6	7	7		21	156	7.42
3	6	5	7		5	13	5	1		5	5	6	6	10	6		4		3	10	8		17	105	6.17
4	4	1			3		4			3	3	4	5	6			2		2	3	2		13	42	3.23
5							5			2	3	2							2	6			6	20	3.33
6							2				2	2							2	3			5	11	2.20
7																				2			1	2	2.00

sented in Table I. In the first column are listed the successive extinctions. In the following columns are presented the number of stimulations per extinction for the various animals, and in the last 3 columns are listed, respectively, the total number of cases in each extinction, the total, and the average number of stimulations required per extinction.

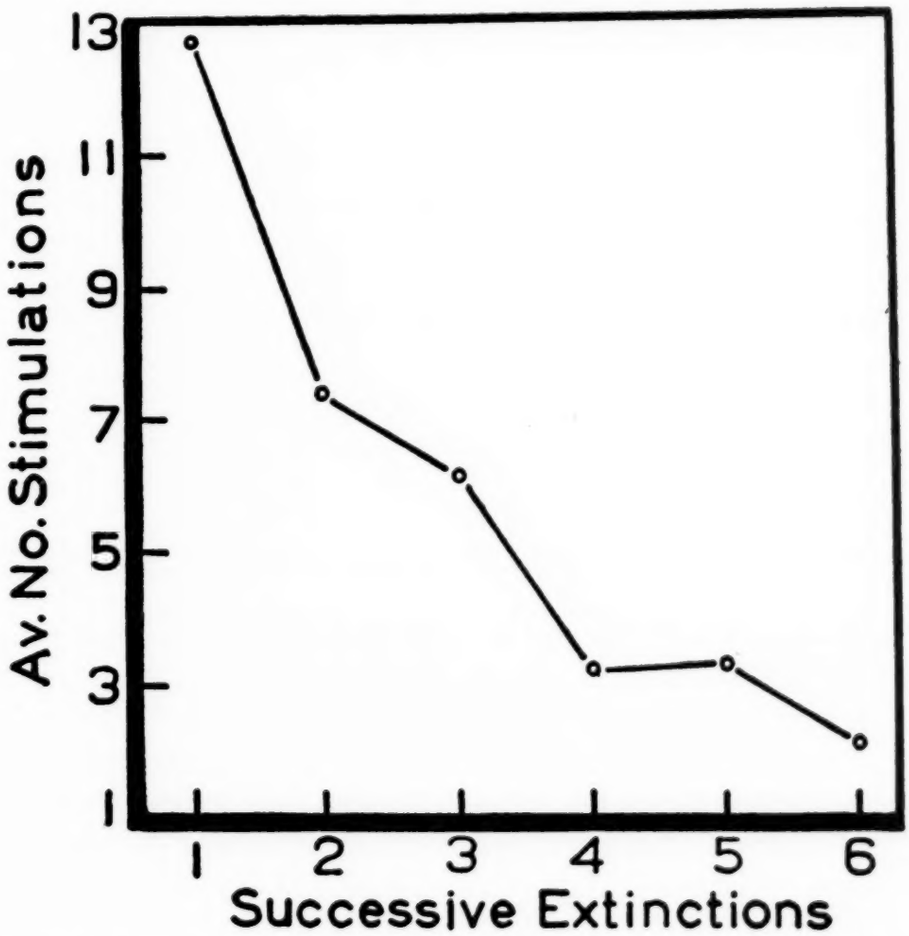

FIG. 1. The curve of extinction for the tail reflex of the spinal rat. Average number of stimulations necessary for extinction is plotted as a function of successive extinctions. Results are for 11 animals from whom 21 extinction series were obtained. Stimulation occurred at 15-second intervals.

An examination of the averages presented in the last column shows that for each successive extinction a smaller number of stimulations is required. Thus, the average number of stimulations required for the first extinction is 12.71, for the second 7.42, for the third, 6.17, etc. It should be noted that successive extinctions, after the first 2, represent progressively fewer cases. This is due to the fact that animals differ in the number of extinctions required for the complete extinction series. In some animals the response disappeared

TABLE II

MAGNITUDE OF RESPONSE IN MM OF THE TAIL REFLEX OF THE SPINAL RAT AS A FUNCTION OF SUCCESSIVE STIMULATION FOR EACH OF THE FIRST FOUR EXTINCTIONS

Stimulus	1st Extinction			2nd Extinction			3rd Extinction			4th Extinction		
	Total No. Cases	Total Magnitude	Av. Magnitude	Total No. Cases	Total Magnitude	Av. Magnitude	Total No. Cases	Total Magnitude	Av. Magnitude	Total No. Cases	Total Magnitude	Av. Magnitude
1	21	106.40	5.06	20	66.00	3.14	17	35.50	2.09	13	17.00	1.30
2	21	81.00	3.85	21	53.50	2.54	16	26.00	1.60	12	13.50	1.10
3	21	58.50	2.78	21	47.00	2.23	16	21.00	1.30	9	7.50	.83
4	21	60.00	2.85	20	31.50	1.50	15	19.50	1.30	5	4.50	.90
5	21	47.50	2.26	18	33.50	1.86	13	13.50	.96	2	1.50	.75
6	21	38.00	1.80	15	23.50	1.56	9	11.00	1.20	1	.50	.50
7	20	45.00	2.25	12	16.50	1.37	5	5.00	1.00			
8	19	30.00	1.57	6	7.00	1.17	4	5.50	1.39			
9	14	22.50	1.60	4	5.00	1.25	3	7.00	2.30			
10	13	24.00	1.84	4	3.50	.87	3	3.00	1.00			
11	12	19.00	1.58	3	2.50	.83	1	1.00	1.00			
12	11	18.00	1.63	3	3.00	1.00	1	1.00	1.00			
13	10	17.50	1.75	3	3.00	1.00	1	1.00	1.00			
14	10	12.50	1.25	2	3.00	1.50						
15	8	12.00	1.50	2	1.50	.75						
16	8	9.00	1.12	1	.50	.50						
17	5	7.00	1.40									
18	4	6.00	1.50									
19	3	3.50	1.16									
20	1	2.00	2.00									
21	1	1.50	1.50									
22	1	2.00	2.00									
23	1	1.50	1.50									

completely in 2 extinctions, in others it remained for 7 successive extinctions.

There is, apparently, no relationship between the number of stimulations required for the first extinction and the total number of extinctions obtained in a series. Animal No. 8, for example, shows extinction series containing 2, 6, and 7 extinctions, yet the number of stimulations required for the first extinction in each series is about the same (16, 16, and 11).

Figure 1 presents the average number of stimulations plotted against successive extinctions. Each point on the curve represents

the average of no fewer than 5 cases of extinction. The curve is negatively accelerated.

Extinction of the tail reflex may be described also in terms of the magnitude of response measured in mm of deflection on the kymograph record. The results are presented in Table II for each of the first 4 extinctions. The first column indicates successive stimulations. Then is presented for each of the extinctions the number of cases per stimulation from which a response was obtained, the total magnitude of the successive responses for the respective cases, and

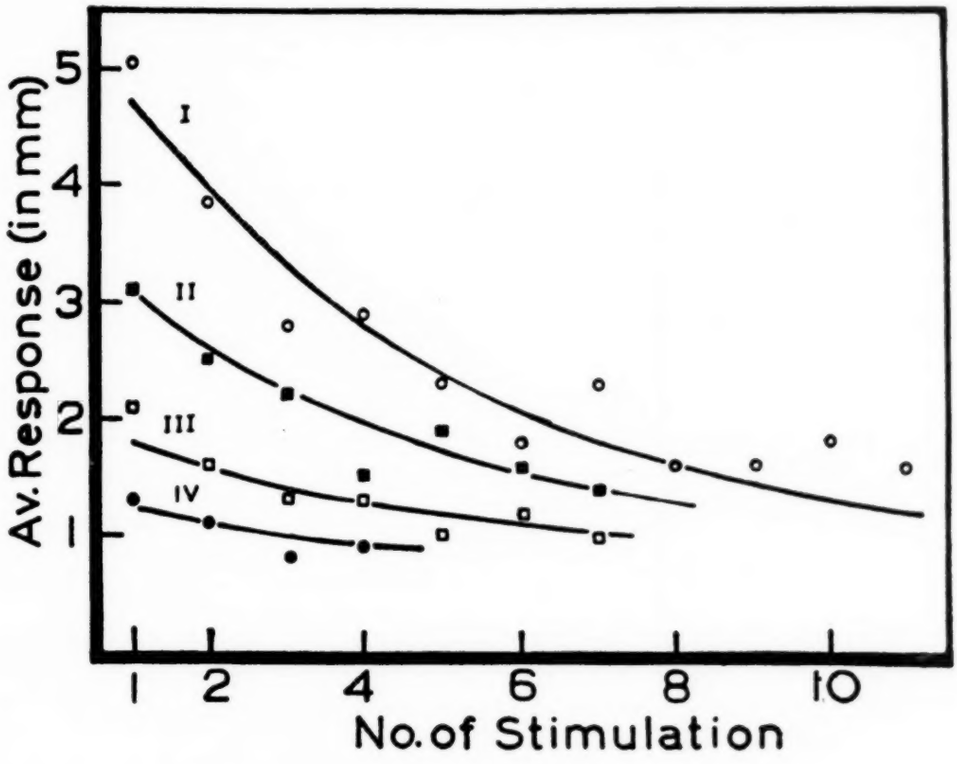

FIG. 2. Curves for the first, second, third, and fourth extinction of the tail reflex in the spinal rat. Average response magnitude (in mm) is plotted as a function of successive stimulations in each extinction. Stimulation occurred at 15-second intervals. The curves, which are parallel along the abscissa, represent an empirical expression discussed later in the text.

the average magnitude of response. The second extinction refers to the responses obtained following application of the disinhibiting stimulus after the first extinction, the third extinction to the responses obtained following application of the disinhibiting stimulus after the second extinction, etc. The magnitude of response for the fifth, sixth, and seventh extinctions are not given because, as can be seen from Table I, only 6, 5, and 1 cases, respectively, showed that number of successive extinctions.

When average magnitude is plotted as a function of successive responses for each of the 4 extinctions we obtain the curves given in

Fig. 2.[3] The general trend of all the curves is one of negative acceleration. This negative acceleration becomes progressively less, however, from the first to the fourth extinction. The curves are parallel along the abscissa and can be superimposed, suggesting that they are all parts of a more general extinction process. The formulation according to which these data were fitted will be discussed later.

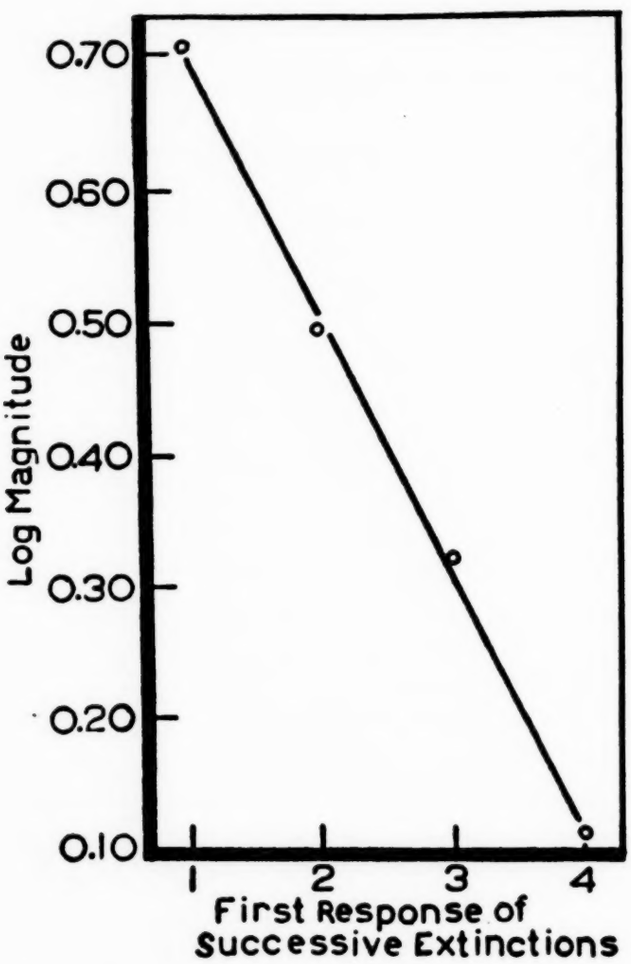

FIG. 3. Extinction curve of the tail reflex of the spinal rat. Log magnitude of the first response is plotted as a function of successive extinctions.

The progressive decrease in negative acceleration as shown in Fig. 2 can be accounted for in terms of the progressively decreasing recovery of each successive extinction to the disinhibiting stimulus. To obtain a clearer view of the extent of successive recoveries to the disinhibiting stimulus the average log magnitude of the first response was plotted as a function of the successive extinctions. These results, presented in Fig. 3, give a straight line, indicating that the extent of successive recoveries to a disinhibiting stimulus is in the nature of a logarithmic function.

[3] Actually these curves represent a theoretical formulation (*cf.* p. 451); they may be taken here, however, to indicate the trend of the experimental results.

The data in Table I were examined for a possible transfer effect of extinction from one day to another. No definite conclusions can be drawn from the present work, for in only three cases (rats Nos. 2, 3, and 5) were complete extinction series obtained on immediately successive days under the conditions set for the present experiment. In these cases no transfer effect is apparent as measured in terms of total number of stimulations per extinction series, or in terms of number of stimulations required for the first extinction of the series on successive days. A comparison of the results for all animals likewise indicated the absence of a carry-over effect. The mean number of stimulations required on the first day was 27.43, for a following (not necessarily successive) day, 33.57, and for the final day, 29.00. A comparison of the magnitude of response for successive days shows a similar absence of transfer effect.

In summary: Repeated elicitation of the tail reflex at 15-second intervals results in extinction. This extinction can be disinhibited by the application of an extraneous stimulus, in this case a pinch of the tail. The curve of extinction, whether extinction is measured in terms of number of stimulations required or in decreased magnitude of response, is negatively accelerated. Successive extinctions in a series show progressively less negative acceleration, recovery being less and less for each disinhibition.

Abdominal Reflex of Man

A typical superficial or cutaneous reflex is the abdominal reflex in man, elicited by a rapid stroke on the abdomen with a pointed object. Various reflexes may be obtained, depending upon which part of the abdomen is stimulated: (1) the epigastric reflex, elicited by a stroke above and along the costal margin; (2) a supraumbilical abdominal reflex, elicited by a stroke above the umbilicus; (3) an umbilical abdominal reflex, elicited at the level of the umbilicus; and (4) an infra-umbilical abdominal reflex, elictied by a stroke below the umbilicus. Each of these may be obtained from either the right or left side.

There is no agreement in the literature on whether or not the abdominal reflex can be extinguished. Monrad-Krohn (**10**) states: "Normally exhaustion of the abdominal reflex is as a rule not noticeable . . ." (p. 165), while Riddoch (**17**) and Söderbergh (**20**) find that it extinguishes to repeated stimulation. The present investigation was designed to determine whether the abdominal reflex extinguishes and to observe, if it does, the course of this extinction.

Procedure.—Extinction of the abdominal reflex was investigated in 16 male subjects ranging in age from 20–27 years with an average age of 24 years and 4 months. The subjects were normal individuals who showed none of the characteristics which are known to complicate the abdominal response, such as a fat and flabby abdominal wall, striæ gravidarum, and scars.

The reflex studied was the middle or umbilical abdominal reflex. The response involves primarily an ipsilateral contraction of the abdominal muscles, resulting in a deviation of the linea alba and the umbilicus. The reflex was elicited with the subject lying on his back on some solid support. Instructions were given to relax and usually some diversion was offered in the form of reading. This diversion served to guard against anticipation which might occur to the constant stimulating interval. Söderbergh (**20**) points out the necessity for this precaution when he says: "Bisweilen sieht man z.B. die ganze Bauchhälfte sich einziehen und den Nabel sich nach der gereizten Seite zu verschieben—ehe noch die Nadel die Haut berührt hat" (p. 240). The stimulus was a rapid stroking of the skin in a cephalo-caudal direction 2½ inches to the side of the umbilicus with a cutaneous stimulator, applied manually at 15-second intervals. The area stimulated was about 2 inches in length. (The reflex can also be elicited by a transverse stroke, either towards or away from the middle line, at the level of the umbilicus; but the cephalo-caudal stroke was used here because it produces less skin distortion to interfere with a recording of the reflex.) The intensity of the stimulus was roughly controlled by exerting just enough pressure to bring the spring-like tip of the stimulator in contact with an adjustable guide-screw. The absence of the response to three successive stimulations was taken as the criterium of extinction.

The disinhibiting stimulus was a pat on the abdomen on the previously stimulated area. In some preliminary observations it was found that movement by the subject (*e.g.*, sitting up), or an increase in stimulus strength, or a period of time without stimulation (*i.e.*, spontaneous recovery) served to restore the extinguished response. In the results presented here, however, only the pat on the abdomen was used as a disinhibiting stimulus.

Some recordings of the reflex were made on a kymograph, using a thread attached by means of adhesive tape to the spot on the skin where movement appeared greatest. The thread was run over a pulley to a marker in such a manner that it mediated the relatively large transverse component of the abdominal reflex, but since this manner of recording interfered with the response the method was discontinued.

Results.—The extinction of the abdominal reflex will be described in terms of the number of required stimulations. Sixteen subjects were used and from these a total of 92 extinction series were obtained. Seventy-five of these were obtained from the right side of the abdomen, the other 17 series from the left side. All the extinctions from the left side were obtained immediately after the reflex from the right side had been extinguished. This was done to check on a possible transfer effect in which extinction of the right abdominal

TABLE III

NUMBER OF STIMULATIONS PER EXTINCTION OF THE ABDOMINAL REFLEX IN MAN

No. of Ext.	Total Ext.	Total Stim.	Av. No. Stim.
1	92	1842	20.02
2	92	890	9.67
3	88	466	5.29
4	55	178	3.23
5	31	62	2.00
6	10	15	1.50
7	2	2	1.00
8	1	1	1.00

reflex would affect the extinction of the left abdominal reflex. A comparison of the average number of stimulations required per extinction for the left abdominal reflex with those required for the right abdominal reflex shows no significant differences. In the absence of evidence for a transfer effect, the data for the left and right reflex are combined. These data are presented in Table III. In the first column are presented the number of successive extinctions, in the second column the total number of extinctions obtained from the 16 subjects per successive extinction, and in the third and fourth columns, respectively, the total, and the average number of stimulations per extinction. Thus, the average number of stimulations required for the first extinction is 20.02, for the second, 9.67, etc. Graphic representation of these results is given in Fig. 4, where the average number of stimulations is presented as a function of successive extinctions. The curve is negatively accelerated and is similar to the one presented in Fig. 1 for the tail reflex of the rat.

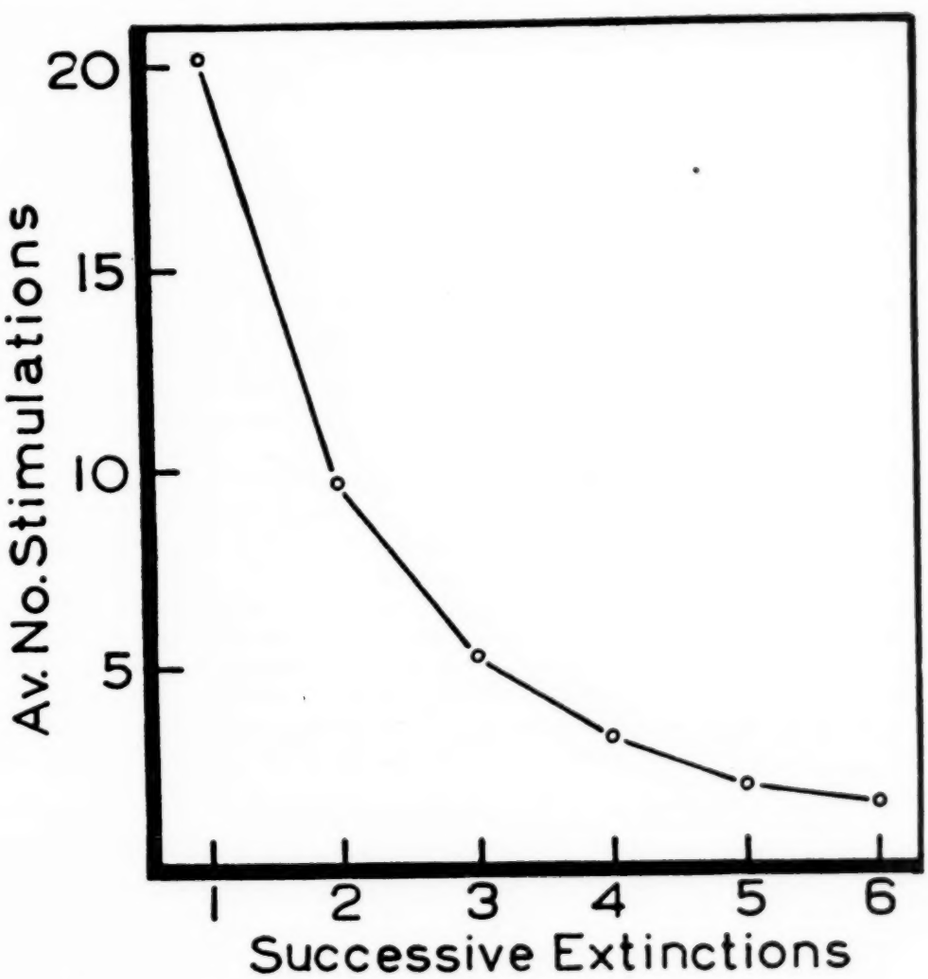

FIG. 4. The curve of extinction for the abdominal reflex of man. Average number of stimulations necessary for extinction is plotted as a function of successive extinctions. Results for 16 subjects from whom 92 extinction series were obtained. Stimulation occurred at 15-second intervals.

Reaction time measurements of the reflex were made by placing two small pad electrodes on the abdomen, over the area showing the maximum response to stimulation, and recording the muscle potentials by means of resistance and capacity-couples amplifiers and a Westinghouse oscillograph.[4] The reaction time values obtained varied between 0.06 and 0.09 second, with a mean of 0.07 second. These values are slightly lower than those obtained by Herzog (**6**), who gives a range of 0.08 to 0.13 second (no mean value given). No change in reaction time was observed during extinction.

In summary: Successive elicitation of the abdominal reflex at 15-second intervals from a constant stimulus locus results in extinction. Presentation of an extraneous stimulus, *e.g.*, a pat on the abdomen, produces disinhibition, and successive extinctions following disinhibition follow a negatively accelerated curve. There is no evidence of a transfer of extinction from the right abdominal reflex to the left. Reaction time measurements gave an average value of 0.07 second, with no changes accompanying extinction.

Startle Response of the Rat

Procedure.—The extinction of the startle response to an auditory stimulus was studied in 11 female and 4 male rats (normal) about 4–6 months of age. Each animal was restrained by means of a holder, and a small rubber balloon which led to a Marey tambour was placed beneath it. The respiratory startle response, which appeared on the record as sharp spikes, was recorded on a wax-paper kymograph. The onset and duration (about 0.5 seconds) of the startle stimulus was recorded simultaneously with the breathing response. This stimulus, consisting of a small electric buzzer located 12 inches from the animal and out of its line of vision, was automatically presented every 15 seconds by means of a telechron motor timing device. The loudness of this buzzer was just above threshold value for the startle response. The disinhibiting stimulus, the intensity of which was roughly controllable and kept as nearly constant as possible, was a pinch on the animal's left hind leg slightly above the knee.

The criterion for extinction was failure of the response to appear to 3 successive stimulations. The disinhibiting stimulus was then applied, and 15 seconds later auditory stimulation was resumed until extinction again occurred. This was repeated until the application of the disinhibiting stimulus was not followed by a response for 3 successive stimulations. All stimulation, whether by buzzer or pinch, was given at the 15-second interval, and only those extinction series are included in the results which were obtained by the above procedure. If, for example, the animal moved during the first extinction and so disinhibited the (partially or completely) extinguished response, it was removed from the experimental conditions and returned to its cage. It was not used again until at least 6 hours later. All animals were subjected to a preliminary habituation period consisting of about 20 minutes restraint on each of 5–6 days prior to the first experimental seison.

Results.—Extinction of the respiratory startle response will be described in terms of the number of required stimulations since no consistent changes in magnitude of response were obtained. In some animals the startle response remained at a more or less constant magnitude until extinction occurred, while in others it showed great

[4] The writer wishes to acknowledge the assistance of Dr. Donald B. Lindsley in taking these measurements.

irregularities. When the response was present it was, more often than not, a maximum response, and when extinction occurred it usually did so suddenly.

Thirty-seven extinction series of the startle response were obtained from 15 animals. As with the tail reflex and the abdominal reflex, one extinction series, consisting of several successive extinctions, was obtained from an animal on any one day. These data are summarized in Table IV. In the first column are presented the num-

TABLE IV

NUMBER OF STIMULATIONS PER EXTINCTION OF THE STARTLE RESPONSE IN THE RAT

No. of Ext.	Total Ext.	Total Stim.	Av. No. Stim.
1	37	1098	29.67
2	37	598	16.16
3	37	404	10.91
4	32	241	7.53
5	27	167	6.18
6	22	102	4.63
7	13	40	3.07
8	8	22	2.75
9	6	15	2.50
10	5	13	2.60
11	2	6	3.00
12	1	2	2.00

ber of successive extinctions, in the second column the total number of extinctions obtained from the 15 animals per successive extinction and in the third and fourth columns, respectively, the total, and the average number of stimulations per extinction.

As seen from the figures presented in the last column, there is a progressive decrease in the number of stimulations required for successive extinctions. The average number of stimulations required for the first extinction is 29.67, for the second extinction (following disinhibition as described previously), 16.16, and so on for the successive extinctions. Because animals differ in the number of extinctions required for the complete extinction series, the successive extinctions, after the first few, represent progressively fewer cases. Thus, the average of the first 3 extinctions is obtained with 37 cases, the fourth with 32, the fifth with 27, etc. The range of successive extinctions for the group is from 3 to 12, with a mode of 6 and a mean of 6.1. The largest range for any one animal is 4 to 10 (animals Nos. 1 and L_2R_2) successive extinctions. There is evidently, as indicated by the data, no relationship between the number of stimulations required for the first extinction and the number of extinctions in that series.

The results of Table IV are presented graphically in Fig. 5, where the average number of stimulations is plotted against successive extinctions. The number of cases averaged for any one extinction can be seen from Table IV. No fewer than 5 cases represent the average of any one point. The curve, like that presented in Fig. 1 for the tail reflex and that of Fig. 4 for the abdominal reflex, is negatively accelerated. A curve of similar slope is obtained also when only

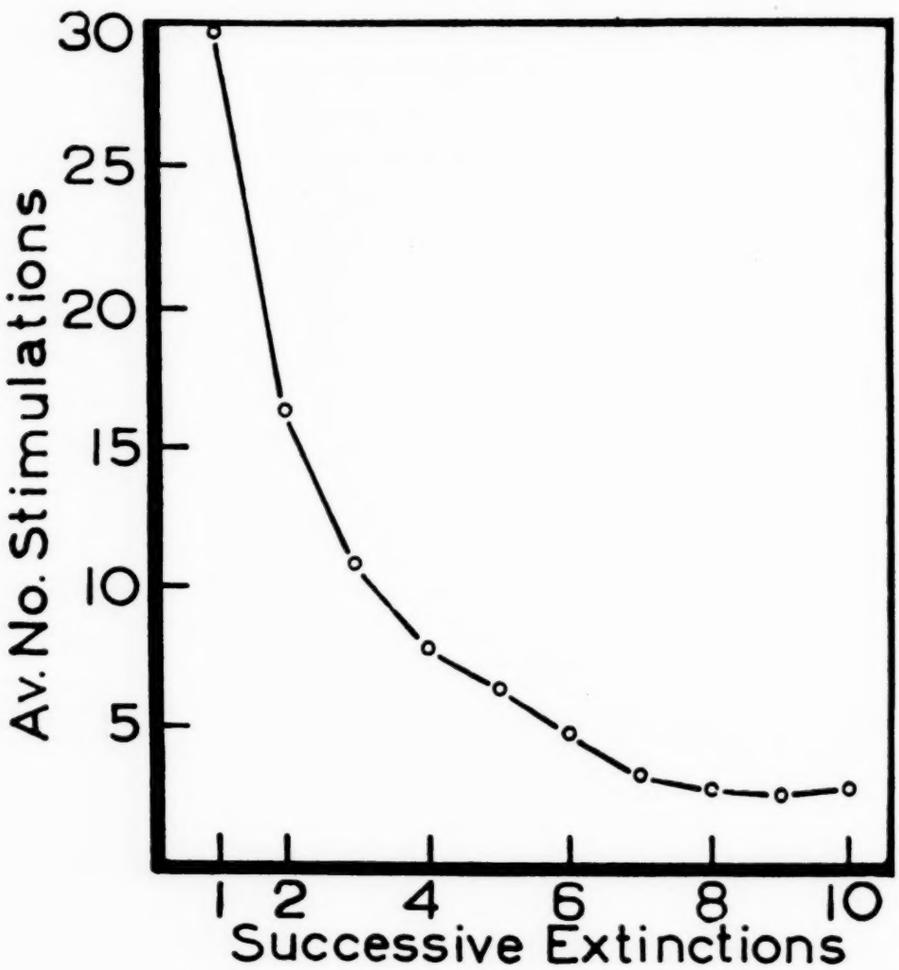

FIG. 5. The curve of extinction for the respiratory startle response of the normal rat. Average number of stimulations necessary is plotted as a function of successive extinctions. Results are for 15 animals from whom 37 extinction series were obtained. Stimulation occurred at 15-second intervals.

those cases are averaged which showed a certain minimum number (*e.g.*, 7) of extinctions, *i.e.*, when each point on the curve represents the average of the same number of cases.

The data were examined for evidence of transfer of extinction from one day to another. As indicated, an attempt was made to obtain an extinction series from each animal on successive days, but this was possible in only 2 cases. Nevertheless, since some extinction usually occurred in the daily attempted extinction with each

animal, a comparison was made of the total number of stimulations required per extinction series, and the average number of stimulations per extinction series for succeeding days. The total number per series shows no transfer effect. The average number of stimulations for the 3 succeeding extinction series are, respectively, 85.15, 65.15, and 65.88. There is a drop from the first to the next extinction series (representing succeeding, not successive days, except for the 2 cases mentioned above) of 20 required stimulations, but the *t*-test value for the signifficance of this difference is only 1.07, which is not reliable.

Further examination of the data summarized in Table IV indicated a great variability in the number of stimulations required per extinction. This variability is greater for the extinction of the startle response than it is for the tail reflex or the abdominal reflex. In the present results there is a range of 8–195 for the number of stimulations required for the first extinction series, and a range of 19–153 for the number required for the second series, and a range of 26–170 required for the third series. (This great variability is a contributing factor to the low reliability of the differences between the means given above.) Schlosberg (**18**) and Mote (**11**), who were interested in extinguishing the respiratory startle to a buzz or light in pre-conditioning procedure, also noted this great variability. Strauss (**21**), and Landis and Hunt (**9**), working on the startle response with human subjects, also noted it.

Absolute reaction time measurements of the startle response in the rat were not taken. Relative measures, however, of the time interval between onset of the stimulus and the onset of the response can be obtained from the records. These measures show no consistent change as extinction occurs. This is in agreement with the results on the tail reflex of the spinal rat and the abdominal reflex of the human being, and with results obtained by Prosser and Hunter (**14**), who found no increase in latency with repeated stimulation for either the startle response or the tail reflex of the rat. Landis and Hunt (**9**), Strauss (**21**), and several others who have worked on the startle response in human beings, make no mention of a change in latency with repeated stimulation.

In summary: The respiratory startle response of the rat extinguishes to repeated stimulation with a buzzer at 15-second intervals. Disinhibition of the extinguished response can be obtained with an extraneous stimulus but each subsequent extinction occurs more quickly than the preceding one. The curve for extinction is negatively accelerated. There is no evidence of a transfer effect from one day to another. Reaction-time measurements show no change during extinction.

III. Reflexes not Showing Extinction

Several other responses in which no evidence of extinction was obtained were investigated by the following procedures:

Patellar Reflex of the Cat

This reflex was investigated in 3 spinal and 2 normal female adult cats. Using avertin anesthesia, a 2–3 inch incision was made through the skin at the thoracic level, and 2 or 3 dorsal vertebral arches were removed. The exposed cord was then transected with a kinfe. No animal was used within the first four days after operation.

Testing of the knee-jerk was carried out on the left hind leg with the animal lying on its right side. Stimulation was given with a small metal rod which was held in position by an electromagnet and which fell through an arc of 70 degrees, striking the patellar tendon at the same spot throughout the experiment. The pendulum rod was automatically released at 5- or 15-second intervals by means of the telechron timing device. The intensity of the stimulus was just sufficient to elicit the reflex.

Body movements of the animals were restrained by a 2-inch strap which ran across the shoulder of the animal and held it to the table. Each animal was adapted to this restraint in 15-minute periods on each of 4–5 days before experimental work began (in the case of the spinal animals, before the operation was performed). By means of a metric tape placed beneath the animal's leg the magnitude of the knee-jerk could be recorded in cm of excursion.

Biceps Reflex of Man

This reflex was elicited from the partially flexed and relaxed arm by placing the examiner's thumb on the biceps tendon and tapping the thumb with a rubber hammer. This results in a contraction of the biceps. Using threshold intensity, stimulation occurred at 5- and 15-second intervals.

Pupillary Response of Man

An attempt was made to extinguish the direct and the consensual response to a minimal increase in light intensity and the pupillary dilation reflex to a minimal auditory stimulus. A 50-watt Mazda bulb was placed in a light-proof box in front of a silvered concave reflector. The light was 27.5 inches from a right-angled prism, and 44 inches from the eye of the subject. The amount of light striking the eye was controlled by means of a shutter 7 inches from the light. Two fine cross threads placed directly behind the shutter and within the box served for fixation. The eyepiece of a stereoscope with the lens removed was mounted on a supporting rod at a height convenient for the subject. Beneath the eyepiece and also attached to the supporting rod was an individually cast mouthpiece. The pupil was viewed by means of an adjustable Bausch and Lomb telescope fitted with a micrometer ocular which magnified the pupil 5 diameters. By

means of two parallel hairs in the ocular, one of which was movable by means of a micrometer screw, it was possible to measure the size of the pupil by bringing the hairs tangent to the pupil on either side and reading the pupillary diameter directly from the micrometer scale to the nearest 0.1 mm.

The apparatus was set up in a dark room and the subject was dark-adapted for 5 minutes. The subject then focused on the cross-hairs in the light-box with the shutter diaphragm set at an opening of 2 mm. This provided sufficient illumination to observe pupillary changes. When the subject was stimulated this opening was increased to 3 mm, an increase sufficient to elicit a just noticeable response and one which could definitely be considered as contraction to stimulation against a background of the constantly fluctuating pupillary periphery. Four male subjects were used. Three were graduate students and the fourth was 13 years of age. The subject was seated at the apparatus and given the following instructions: "Sit quietly and adjust your head as firmly and as comforably as possible while you fixate with one eye [except for investigation of the consensual reflex, when the covering over the opening for the other eye was removed] on the cross-hair you see directly before you. Make an effort to remain as quiet as possible. Don't move. Don't wink oftener than you absolutely have to. Maintain fixation as long as you can."

In studying the consensual reflex, the indirect response observed in one eye upon stimulation of the other eye, the procedure remained as already described, but the covering over the opening for the unstimulated eye was now removed and the telescope focused upon this eye. In order to observe the pupil a small hole (about 2 mm in diameter) was drilled through the eye-shield so that the light from a small 2-volt flashlight bulb could be focused upon the extreme outer periphery of the eye, where it has been shown to have very little, if any, effect upon pupillary contraction (7).

Pupillary dilation to auditory stimulation was investigated because it was thought that the auditorily controlled reflex, which is mediated by a different neurological mechanism (**23**) from the light reflex, might show some extinction. The procedure was similar to that described above except that a sound-stimulus was presented instead of the light-stimulus. The sound was produced by a buzzer whose intensity was adjusted to threshold value for a measurable response.

Results.—The data for these reflexes are summarized in Table V. In it are presented the number of stimulations presented at 3-, 5-, and 15-second intervals. Each figure represents the number of successive stimulations given without interruption by any factor which might have served as a disinhibitor. Thus, the first figure for spinal cat No. 1 indicates that 264 stimulations were given at 15-second intervals, at which point some interruption occurred and stimulation ceased. In a few instances the animal remained quiet for as many as 1,500 stimulations, when stimulation was terminated. Each figure represents the experimental session for one day. No extinction was observed.

For the biceps reflex in man, the largest number of stimulations presented at the 15-second interval was 400; the largest number at the 5-second interval was 600. In one instance, second series for subject S, 400 stimulations were given at the 15-second interval, followed immediately by 500 stimulations at the 5-second interval, making a total of 900 stimulations for a single series. No extinction was observed.

The data for the pupillary reflex likewise fail to show any extinction. Each number here also represents the experimental session for a day, but the total number of stimuli presented were not given in uninterrupted succession. Discomfort of the subject with prolonged stimulation necessitated short rest-periods, usually 1–2 minutes duration. The largest number of stimulations given without interruption

TABLE V

NUMBER OF RESPONSES OBTAINED AT 3-, 5-, AND 15-SECOND INTERVALS FROM VARIOUS REFLEXES WITHOUT EVIDENCE OF EXTINCTION

	Subject	Stimulation Interval							
		15 sec.			5 sec.			3 sec.	
Patellar Reflex									
Spinal Cat	1	264	300	194	371	316	204		
	2	1000	255	455	1300	600	389		
	3	291	400	409	1500	1100	1500		
Normal Cat	R_1		193	234		321	280		
	R_2		346	317		437	454		
Biceps Reflex	*S*	300	400	240	600	500	500		
	C	250	300	200			300		
	M			350					
Pupillary Contraction									
Uniocular	*R*			249		588	566	484	480
	B			247			800		506
	M						506		
	W		325	284					
Consensual	*R*		214	269			285	460	505
	B			375			340	594	520
Pupillary Dilation	*R*		195	296		326	267		
	S			335			495		512
	T			286					532

was 200 at a 5-second interval. The largest number given in any one series, which constituted a day's session, was 800 (subject *B*). No extinction was observed in uniocular or consensual pupillary contraction to increased light intensity, nor to pupillary dilation to minimal sound stimulation.

IV. Discussion

Most discussions and theories of conditioning proceed, implicitly (*e.g.*, **13**) or explicitly (**5**), on the assumption that the effect of the unconditioned stimulus under standard conditions is always the same. This may be true for such reflexes as the patellar reflex, the plantar reflex, or the pupillary reflex, but it is not the case in the tail reflex

and the startle response of the rat or in the abdominal reflex of the human being. In the tail reflex, for example, it has been shown that the magnitude of response under standard conditions is a function of the immediately preceding history of the response, and successive elicitation of the unconditioned reflex results in a decrease in the magnitude of the reflex. Recovery from this decrement has been shown to take place as a function of such factors as an increase in strength of the stimulus, a change in locus of stimulation, a change in type of stimulus, or a period of time during which no stimulation is given (*cf.*, *e.g.*, **1**, **2**, **8**, **14**).

It is not the aim of the present paper to present an hypothesis concerning the mechanism of this decrement but rather to describe the changes that have been observed. Thus, for descriptive purposes it should be emphasized that the course of this decrement presents a regular trend and may be described by a simple relationship such as that shown in Figs. 2 and 6. In Fig. 2 average magnitude is plotted as a function of successive responses for each of 4 extinctions of the tail reflex. The general trend of the curves is one of negative acceleration. The four curves can be superimposed and plotted on the same coördinates by shifting the curve for the second extinction 2 abscissa units, that of the third extinction 5 abscissa units, and that of the fourth extinction 7.2 abscissa units.

The slope of the curves is such that

$$\frac{\frac{\Delta R}{\Delta M}}{R - R_t} = -k. \tag{1}$$

Passing to the limit, we get

$$\frac{dR}{dM} = -k(R - R_t), \tag{2}$$

which, integrated, gives us the expression

$$(R - R_t) = (R_0 - R_t)e^{-k(M-1)}, \tag{3}$$

where R is the magnitude of response, R_t the threshold value of R, R_0 the magnitude of the first response, and M the successive number of stimulations per extinction, and e base of the natural log. The adequacy of fit can be seen from Fig. 2, where the curves drawn through the data are calculated on the basis of equation (3) with appropriate values of R_0.

Extinction has been described above in terms of average magnitude as a function of successive responses. It may, however, also be described in terms of average number of stimulations required per successive extinction. The course of decrement again shows a regular trend, as indicated in Fig. 6, where the results for the tail

reflex, the startle response, and the abdominal reflex are presented. The results for the three reflexes are plotted on the same coördinates, and the curves are superimposed by shifting the curve for the abdominal reflex one abscissa unit and that of the tail reflex 2 abscissa units. From the similarity of slope it appears that the same general

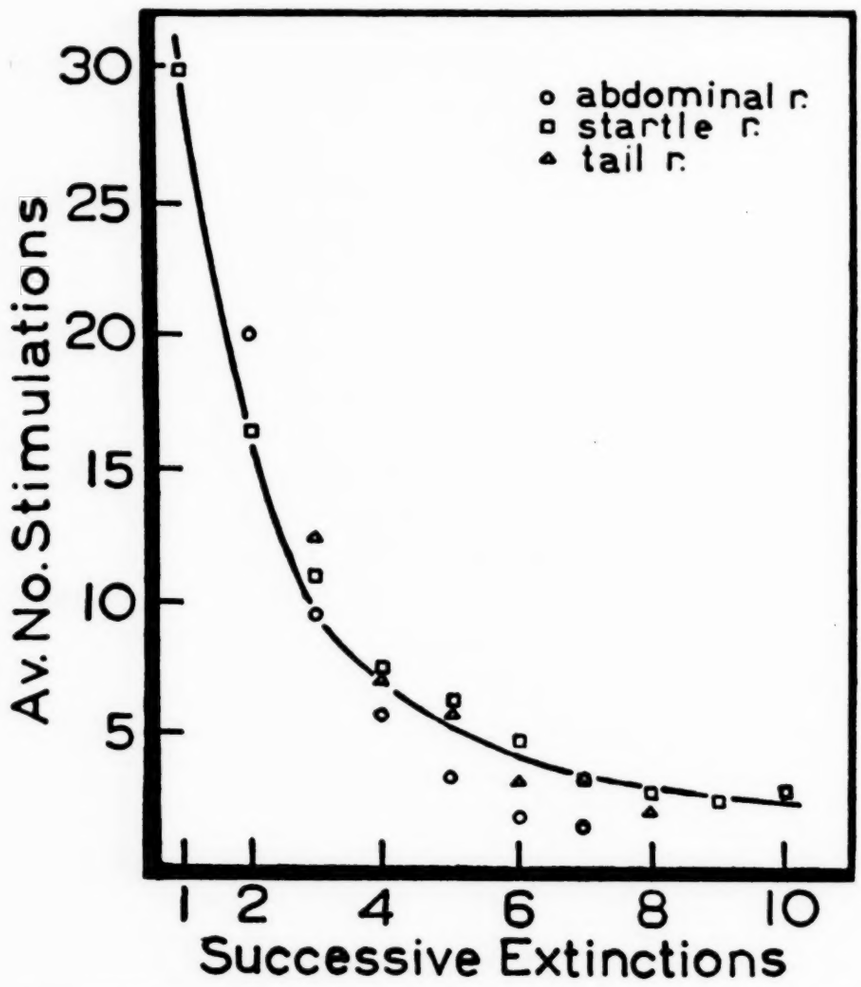

FIG. 6. Extinction trend for the abdominal response of man, the respiratory startle response of the normal rat and the tail response of the spinal rat when average number of stimulations necessary for extinction is plotted as a function of successive extinctions. The results for the 3 responses are fitted by the same curve if the points for the abdominal response are shifted one absicssa unit and those of the tail response two abscissa units.

type of curve fits the 3 sets of data, and that the curves differ from each other only in an arbitrary abscissa constant. An examination of the slope of the curve indicates that the relative change in N, the number of stimulations, to the relative change in E, successive extinctions, is a constant, *i.e.*,

$$\frac{\frac{\Delta N}{N}}{\frac{\Delta E}{E}} = n. \qquad (1)$$

Passing to the limit, we get

$$\frac{dN}{N} = -n\frac{dE}{E}, \tag{2}$$

which, integrated, gives us the expression

$$N = C(E + E_0)^{-n}, \tag{3}$$

where N is the number of required stimulations, C and n are constants, E the number of successive extinctions, and E_0 an abscissa constant characteristic of a particular reflex. The expression of equation (3) has been fitted to the data for the startle reflex but it also fits, as an approximation, the data for the abdominal and tail reflexes. The specific equation for the data of the startle reflex is

$$N = 30(E + E_0)^{-1.1}. \tag{4}$$

The exponent -1.1 in equation (4) makes the expression very similar to an hyperbola, where the exponent is -1.0. However, because of the empirical nature of the formulation it is thought desirable to keep it in the more flexible power function form.

With respect to general slope, the extinction curves obtained for the three unconditioned responses studied here show a high degree of similarity to the curves of extinction obtained with conditioned responses by Switzer (**22**), for example, on the extinction of the GSR to a conditioned light stimulus where the unconditioned stimulus was an electric shock. Switzer's curves, like the present ones, are negatively accelerated.

Beritoff (**1**) and Pavlov (**13**), of course, specifically express the view that extinction phenomena of unconditioned and conditioned reactions are fundamentally the same. And evidence is available that both are mediated by the same physiological mechanism. Thus, Prosser and Hunter (**14**), investigating unconditioned reflexes in the spinal rat, conclude that "extinction and disinhibition occur beyond the sensory neurone and ahead of the final motoneurone, presumably at some of the internuncial synapses" (p. 616). Shurrager and Culler (**19**), working on conditioning and extinction in the spinal dog, suggest that the synapses of the motoneurones are the loci of both conditioning and extinction.

Some writers have considered extinction as a special type of learning. This view has been expressed by Dodge (**4**), Humphrey (**8**), Mowrer (**12**), Razran (**16**), and others, who have indicated the similarities between habituation and learning. Humphrey, for example, specifically grades learning into various types, ranging from the simplest, which is negative adaptation or extinction, to the more complex, such as maze, and puzzle-box behavior. Between these

two and "representing an intermediate stage in complexity both of stimulus and reaction falls the conditioned response" (**8**, p. 112). The differences between these types of learning are believed by Humphrey to be purely quantitative in nature, merely a matter of complexity (p. 115).

To the question as to whether a reflex will extinguish there is as yet no definite answer. Various factors have been suggested as determining variables. Prosser and Hunter (**14**) offer evidence which suggests that extinction depends on internuncial connections. They obtained extinction of the tail reflex and startle response, each of which is believed to have internuncial neurones, but failed to obtain it in the knee-jerk, which is believed by some to have no internuncial cells. They conclude that "extinction and disinhibition occur . . . presumably at some of the internuncial synapses" (p. 616). However, in the present investigation, neither the plantar reflex, which is believed to have a cerebral arc, nor the pupillary reflex, which is mediated through several synapses, showed extinction. Type of reflex, *i.e.*, tendon or cutaneous, is apparently not a differentiating variable, for extinction was obtained with both types. Nor do other factors which have been suggested—such as an intact organism; level of response, phylogenetically or physiologically considered; strength of response; or biological significance of the stimulus for the organism —account for what reflex will or will not extinguish. At present we can only say that extinction depends, among other factors yet to be determined, on (1) intensity of stimulus, (2) rate of stimulation, (3) constant locus of stimulation, and (4) absence of extraneous disinhibitors.

Summary

The present investigation was undertaken to study the extinction of unconditioned responses to the repeated presentation of a stimulus at intervals which preclude sensory adaptation, motor fatigue, or inhibition in the Sherringtonian sense of the word. It was hoped that information might also be obtained concerning the kind of responses which could be extinguished. Several different responses were studied. Deep or tendon reflexes which are mediated through a spinal arc were studied in the form of the tail reflex in the spinal rat, the patellar reflex in the spinal and normal cat, and the biceps reflex in the human being. Superficial or cutaneous reflexes which have cortical representation are represented by the plantar and the abdominal reflex in the adult human being. In addition two other responses were studied: the respiratory startle response in the rat, and the pupillary response in the human being.

Investigation of these responses was carried out under comparable conditions, the stimulus in each case being just supraliminal for the response in question, and presented at a constant interval of 15 seconds. The effect of an extraneous stimulus on an extinguished response was also noted. Extinction was measured in terms of number of stimulations required and in terms of change in magnitude of response.

The results show that the tail reflex, the abdominal reflex, and the startle response extinguish. The extinction curve in each case is negatively accelerated. An extinguished response can be disinhibited, but recovery of the response to successive extinctions and disinhibitions is a progressively decreasing proportion of its previous strength, until finally extinction is so complete the disinhibiting stimulus is no longer effective. Extinction is not accompanied by changes in reaction time.

A comparison of the extinction curves of these reflexes shows them to be similar in slope, differing from each other only in an arbitrary abscissa constant. They are apparently fitted by the same general type of curve.

The extinction curves here obtained for unconditioned responses show a high degree of similarity to the extinction curves of conditioned responses.

It is not possible to say definitely what physiological factors underlie the phenomenon of extinction, nor why some reflexes extinguish and others do not. Whatever the organismic factors, the environmental variables apparently related to the phenomenon are intensity of stimulus, frequency of stimulation, constant locus of stimulation, and absence of extraneous disinhibitors.

(Manuscript received May 6, 1941)

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FURTHER STUDIES OF CONDITIONED VASOMOTOR RESPONSES IN HUMAN SUBJECTS[1]

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1. *The Problem.*—The conditioning of vasomotor responses in human subjects has been described by the present writer in an earlier paper (**9**). The method of conditioning, as previously set forth, was to excite vasoconstriction by stimulating one hand with ice-water and to accompany this response with some substitute stimulus, such as that provided by a pattern of light. A thermopile attached to the dry hand furnished continuous measures of skin temperature. A fairly regular fall in temperature of the dry hand occurred with the cold stimulation of the other hand, presumably due to a bilateral reflex action.

In 12 out of the 14 subjects of this previous investigation there was evidence of conditioned vasoconstriction (fall in temperature) following repeated pairings of the cold and the substitute stimulus. Some subjects were conditioned to the sound of a buzzer and to their own verbal activity, others were conditioned to proprioceptive stimuli, or to a visual pattern. In 3 subjects, out of 4 tested, there was some evidence of conditioned vasoconstriction with recall of the visual pattern (imagery), although the cold had been combined only with the visual pattern itself and not with the recall.

The experiments to be described in the present paper were essentially an extension of the earlier study for the purpose of obtaining more complete information on certain problems. Among the problems was that of determining to what degree, if at all, the prolonged repetition of a stimulus (light, vocal, or light-vocal) might of itself, without benefit of conditioning, strengthen the tendency of the stimulus to excite vasomotor responses. A related problem was that of determining the possible influence (upon subsequent vasomotor responses to one of the above mentioned stimuli) of the protracted repetition of the cold stimulus. In other words, the question was whether repeating either the substitute stimulus, or the original stim-

[1] These experiments were carried out in the Psychology Laboratory of the University of Wisconsin. I am especially indebted to Dr. Samuel P. Hayes, Jr., of Young and Rubicam, Inc., New York, N. Y., for his generous assistance in the preparation of the manuscript. Also I wish to express my appreciation to Dr. Lynn E. Baker, of the Census Bureau, Washington, D. C.; to Dr. Lillian Dick; and to Dr. Louis Long, of the College of Physicians and Surgeons, New York, N. Y., for valuable suggestions. Thanks are due to Professor Hulsey Cason who first encouraged and aided the study of vasomotor conditioning.

ulus, would alone produce response modifications, and if so, how these would compare with the changes following the pairing of the substitute stimulus and the original stimulus. Thus, it was hoped to avoid a confusion of the effects of sensitization with those of conditioning.

Another purpose was to secure more data on vasomotor responses occurring during recall of the light (imagery) before and after combining the light itself with the cold.

A further objective, and one not pursued in the original investigation, was to compare the conditioning achieved with a simple stimulus and with a compound stimulus. The subject's vocal activity was combined with the light to give the compound stimulus.

The methods of conditioning, and the experimental techniques in general, of the present study were essentially the same as in the earlier one. Although experience had provided many suggestions for improvement, the temptation to introduce variations was resisted in favor of obtaining comparable data from the two investigations.

2. *The Subjects.*—Observations were made on 22 men, of whom 9 were control subjects, and 13 experimental subjects. Ages ranged from 18 to 30 years. Men were chosen in preference to women on the basis of the previous experiments in which the men usually proved to be the more satisfactory subjects in terms of vasomotor responses to the cold stimulus (**9**, pp. 88–89).

The subjects were generally unaware of the purpose of the experiment.

3. *The Apparatus.*—The essential apparatus consisted of a thermopile and a high-sensitivity galvanometer. The thermopile was bound firmly (by means of adhesive plaster) to the surface of the skin at the thenar eminence of one hand. A thermostatic control chamber provided a constant air temperature surrounding the hand. Air temperature was held somewhere between 15° and 18° C., depending upon the subject's sensitivity to cold.[2]

Room temperature was maintained at approximately 25° C. by thermostatic control. No attempt was made to control humidity.

The reader is referred to the earlier paper for a more detailed description of the apparatus (**9**, pp. 80–83).

4. *The Stimuli.*—The *original* (*unconditioned*) *stimulus* for vasoconstriction was ice-water, of a temperature between 2° and 7° C. Immersion of one hand to the wrist in this cold water resulted in a quite uniform fall in temperature of the other hand. Warm water, of a temperature between 35° and 45° C., was used following the cold, in order to restore the vessels of the hand to the previously dilated state. A continuous kymographic record of skin temperature changes was obtained from the dry hand by means of the thermopile and galvanometer.[3]

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[2] The air temperature of this control chamber was a critical factor. With the temperature between 20° and 26° C. there was, as a rule, little or no galvanometric change during stimulation of the opposite hand with cold, whereas with the temperature in the neighborhood of 15° a marked deflection usually occurred with the cold stimulation.

[3] Fall and rise in skin temperature were interpreted as evidence of vasomotor responses. A fall in temperature was taken to indicate vasoconstriction, a rise to indicate vasodilation. It is realized, of course, that changes in skin temperature are by no means exclusively dependent upon vasomotor reactions. However, under the conditions of this experiment, with the surrounding atmosphere of practically constant temperature, with the subject in a resting condition, and with minimal movements of the skeletal muscles, it seemed reasonable to assume that sudden changes in the skin temperature were functions of vasomotor reactions, particularly when these changes were quite regularly associated with the presentation of the experimental stimuli.

Incidentally, it should be observed that 'vasodilation' as used in this paper does not neces-

The *substitute* (*conditioned*) *stimuli*, or, more properly speaking, stimulus-situations, were:

(*a*) Looking at a pattern of light (hereafter called *light stimulus*).
(*b*) Looking at a pattern of light while whispering a word (hereafter called *light-vocal stimulus*).

One group of subjects was conditioned to situation (*a*), another to situation (*b*).

The light was produced by a 40-Watt electric globe, of blue color, behind a stencil of the pattern X X. These two blue crosses covered an area 2½ by 5 inches, and were displayed at the subject's eye-level at a distance of 5 feet from the eyes.

In situation (*b*) the subject repeated the word 'crosses' in a just audible whisper while looking at the illuminated crosses. Usually the word was repeated at about 4-second intervals, but the rate of repetition and the intensity of utterance were varied with different subjects, in order to avoid, as far as possible, any interference with the normal rate of respiration.

5. *Vasomotor Instability.*—The cardiovascular system is normally in a condition of labile equilibrium. The complex adjustments within the system were reflected to some extent in the fluctuations of skin temperature as measured by the thermopile. Careful control of possible sources of disturbance in the laboratory, of external temperature, and of gross movements and tensions in the skeletal musculature of the subject served to reduce, but not to eliminate, fluctuations of temperature.[4]

Several conditions were observed to cause changes in temperature, among these: coughing, yawning, or deep inspiration;[5] muscular spasms, especially those affecting the experimental hand; abrupt arousal from somnolence; sudden shifts of attention. The usual reaction was a fall in temperature. Some rough control was obtained of these factors, but obviously such a variable as 'shifts of attention' must be elusive.

Marked temperature changes, typically irregular in nature, occurred in anxious and excited subjects.[6] An effort was made to keep the subject in a calm and relaxed state. In the case of individuals inclined to indulge in emotional reverie, the experimenter attempted to induce neutral mental sets, by quiet conversation, by appropriate instructions, etc.

An occasional subject maintained a fairly constant temperature throughout the control sessions. At the other extreme was the typically 'excitable' subject whose temperature fluctuated frequently and erratically. Most subjects fell in between these extremes.

Further difficulties were met in the search for suitable substitute stimuli. Experience in the earlier study had shown that certain stimuli, notably in the auditory modality, tend to excite vasoconstriction. This effect was observed to be, in part at least, a function of the intensity of the stimulus. Likewise, it had been observed that vocal activity of the subject, at certain rates and intensities, resulted in vasoconstriction. In the present study an effort was made to regulate such variables in order to reduce vasomotor reactions. This effort was not entirely successful, as the control results will show. In the previous study, and in the present one also, it was found that the visual stimulus, by contrast with the auditory and vocal stimuli, tended to excite vasodilation. In some subjects this was a particularly marked reaction. This vasodilation to the

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sarily refer to the so-called active vasodilation, that is, to dilation involving dilator nerves. The inhibition of constriction may produce dilation, as the term is used here.

Mean temperature changes were not determined from the present data. In the previous study it was found that the mean fall in temperature of the hand at the thenar eminence during the conditioning trials was 0.16°. This change occurred with cold stimulation of the opposite hand, generally of 60 seconds duration. The cold stimulus was water of 2° to 7° C. The mean fall during tests of the substitute stimuli, after conditioning, was 0.10° C. (failures of response excluded).

[4] Stürup and collaborators (12) have reported that the immersion of one or two of the subject's limbs in water at 44° to 45° C. produces widespread vasodilation, and thus provides a steady base line from which to elicit vasomotor responses.

[5] Bolton and collaborators (1) observed vasoconstriction following deep inspiration in human subjects, and concluded that this effect depended upon afferent stimulation arising from the expansion of the chest wall.

[6] Mittelmann and Wolff (10) measuring changes in the skin temperature of the fingers with a Hardy radiometer, found that major drops in temperature occurred (as much as 13.5° C.) with experimentally induced emotional stress. It was observed that the magnitude of the temperature change varied greatly in different individuals.

light was, of course, a desirable feature for our experiment, since the opposite response, constriction, was the one to be conditioned. From this point of view the vocal activity was a less desirable substitute stimulus.

Anticipating the results to be presented below, we may describe the skin temperature of the resting subject (when he is free of disturbing stimuli) as in a state of equilibrium, in the sense that the temperature fluctuates fairly evenly about a central level, reflecting the balance of the opposed processes of dilation and constriction. The substitute stimuli, before conditioning, tend to disturb this balance somewhat in one direction or the other. The cold stimulus, however, alters the equilibrium forcibly, exciting a vigorous constrictor response. After repeated dual stimulation with cold and substitute stimulus, the substitute stimulus is able to excite, in some measure, the change formerly produced by the cold alone.

6. *Testing Procedures.*—Before conditioning it was necessary to obtain measures of the extent of the unconditioned vasomotor responses to the light stimulus; to imagery of the light; to the subject's vocal activity; and to the light-vocal (compound) stimulus.

One group of subjects was tested with the light, and for the effects of imagery, as follows:

The subject sat in a relaxed position, with his eyes directed toward the light source. He was cautioned against moving, changing the depth or rate of respiration, yawning, etc. Throughout the testing the thermopile was attached to the right hand.[7]

When the skin temperature had attained a fairly constant level:

(*a*) The X X pattern was lighted for 30 seconds.

(*b*) This was followed by a 20 to 40 second interval of darkness (the duration was varied in random order) which constituted a rest period, but without there being any change in bodily position.

(*c*) Next the subject tried to recall the appearance of the lighted X X. His instructions were to close his eyes at a signal and attempt to get 'a mental picture of the blue crosses.'[8] This effort continued for 30 seconds.

(*d*) This in turn was followed by a rest period of 20 to 40 seconds.

In summary:

(*a*) Light for 30 seconds.
(*b*) Rest for 20 to 40 seconds.
(*c*) Imagery of light for 30 seconds.
(*d*) Rest for 20 to 40 seconds.

This routine was repeated some 15 or 20 times in the course of a session.

Occasionally the subject was given a recess during which he was allowed to move about and to talk. Smoking was forbidden throughout the experiment.

A second group of subjects was tested: (*a*) with the light, (*b*) during vocal activity, and (*c*) with these two stimuli together. These subjects were not tested for imagery of the light.

In summary these tests were as follows:

(*a*) Light for 30 seconds.
(*b*) Rest for 20 to 40 seconds.
(*c*) Repetition of the word 'crosses' for 30 seconds.
(*d*) Rest for 20 to 40 seconds.
(*e*) Light and repetition of the word 'crosses' together for 30 seconds.
(*f*) Rest for 20 to 40 seconds.

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[7] All the data which appear in the tables of this study were obtained from the *right hand* of the subject. The thermopile was attached to the right hand during all the control, the preconditioning, and the post-conditioning tests. During the conditioning, however, the thermopile was on the *left hand*, since the right hand was then immersed in water. These measures were taken from the left hand simply for the purpose of determining the extent of response to the cold stimulus, and they are not given in the tables. The hand bearing the thermopile always rested in the control chamber which was supported on a table just in front of the subject, at waist height.

[8] There appeared to be great individual differences in the ability to achieve clear imagery. No consistent relationship between the reported intensity or clarity of imagery and the nature of the concomitant vasomotor reactions could be discovered.

A session usually consisted of 10 repetitions of this routine, and hence of 10 light, 10 vocal, and 10 light-vocal tests.

7. *Method of Conditioning.*—The routine of conditioning to the light as a substitute stimulus was as follows:

(*a*) The X X pattern was illuminated, and 2 seconds later the right hand was immersed in ice-water. Usually this combination of light and cold continued for 30 seconds. With some slowly responding subjects the period was increased to 60 seconds. Quite uniformly, with application of the cold stimulus to the right hand the thermopile on the opposite hand indicated a fall in temperature.

(*b*) After 30 seconds of cold and light, warm water was substituted for cold, and the light was switched off. The right hand was held in the warm water until the temperature of the opposite hand returned to approximately its original level. This would generally require from 60 to 120 seconds. Occasionally the recovery was much slower, especially toward the close of the training session. When this was the case we did not wait for the full rise in temperature.

TABLE 1

PLAN OF EXPERIMENTS

I Experiment	II Group	III Procedure	IV Number of Subjects	V Stimuli of Control Tests; or of Pre-training Tests	VI Training Stimuli	VII Number of Training Presentations	VIII Stimuli of Post-training Tests
A	Control	1	3	Light; imagery	—	—	—
	Experimental	2	3	Light; imagery	Light and cold	20	Light; imagery
		3	2	Light; imagery	Light and cold	40	Light; imagery
B	Control	4	3	Light-vocal; light; vocal	—	—	—
	Experimental	5	3	Light-vocal; light; vocal	Light-vocal and cold	20	Light-vocal; light; vocal
		6	5	Light-vocal; light; vocal	Light-vocal and cold	40	Light-vocal; light; vocal
C	Control	7	3	Light-vocal; light; vocal	Cold*	40	Light-vocal; light; vocal

* In the case of Experiment C there was no conditioning; the cold was presented alone.

The period of warmth stimulation ended with the reappearance of the light, and 2 seconds later the hand was again immersed in the ice-water, etc.

In summary:

(*a*) Cold water with light for 30 seconds (or 60).
(*b*) Warm water with darkness for 60 to 120 seconds.

As a rule, a training session included 20 repetitions of this routine. One group of subjects completed one training session (20 combinations), another group completed two sessions (40 combinations).

As previously described, one group of subjects whispered the word 'crosses' while looking at the pattern of light. These subjects were conditioned by combining the cold with the light and vocal activity. In all other respects they received the same experimental treatment as the subjects conditioned to the light alone.

Continuous temperature readings were taken from the dry hand during conditioning.

The beakers containing the cold and warm water were handled by the experimenter, and the subject moved as little as possible.

8. *Plan of the Experiments.*—Table 1 outlines the plan of the experiments. Table 2 shows the sequence of sessions in terms of days; also the mean number of tests, or the mean number of conditioning combinations, per session.

TABLE 2

TESTING AND CONDITIONING ROUTINES

Showing the sequence of sessions for each of the seven procedures, and the mean number of tests (or of conditioning combinations) per session *

Experiment	Procedure	Mean Number of Tests (T), or of Conditioning Combinations (CC), per Daily Session									Total Mean Number of Tests
		1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day	9th Day	
A	1	27 T	25 T	28 T	33 T	33 T	—	—	—	37 T	183
	2	39 T	20 CC	34 T	40 T	33 T	—	—	—	34 T	180
	3	40 T	20 CC	20 CC	33 T	42 T	40 T	—	—	33 T	188
B	4	30 T	32 T	30 T	28 T	30 T	—	—	30 T	—	180
	5	30 T	20 CC	30 T	30 T	32 T	—	—	30 T	—	152
	6	31 T	20 CC	20 CC	29 T	29 T	30 T	—	—	31 T	150
C	7	30 T	20 cold	20 cold	30 T	30 T	—	—	—	30 T	120

* A 'session' was a series of observations on one subject extending through approximately two hours of one day. Two or more kinds of stimuli were tested in a session. The mean values of this table include all tests.

The primary purpose of Experiment A was to condition vasoconstriction to the light stimulus. As shown in Table 1, a Control Group of 3 subjects was first given tests with the light, and with the imagery. Table 2 gives some details of this testing. There were tests on 5 successive days, no tests during the next 3 days (6th to 8th days), and final tests on the 9th day. The number of tests per daily session was between 25 and 37, and the number of tests per subject for all sessions was 183. Tests with the light and with imagery are combined in these values.

In addition to the control procedure, there were two experimental procedures in Experiment A. (See Table 1.) The subjects of Procedure 2, 3 in number, were first given pre-conditioning tests with the light and the imagery, then conditioned by combining the light stimulus and the cold 20 times, and finally given a series of post-conditioning tests. Table 2 shows this procedure in more detail. There were 39 tests on the 1st day, followed on the 2nd day by 20 conditioning combinations, with post-conditioning tests on the next 3 days (34T, 40T, 33T), and 34 tests on the 9th day. The total number of tests per subject was 180.

Procedure 3 of Experiment A was essentially the same, excepting for 40 conditioning combinations instead of the 20 of Procedure 2. The details are presented in Tables 1 and 2.

The primary purpose of Experiment B was to condition vasoconstriction to a compound light-vocal stimulus. Tests were made with the light and vocal activity occurring together (compound stimulus), as well as with each of the components separately. The three conditions (light-vocal, light, and vocal) were evenly distributed in number in each session. No tests were made with imagery. Tables 1 and 2 summarize the main features of the testing and the conditioning.

Experiment C was intended to show whether or not the repetition of the cold stimulus alone could influence the frequency of subsequent vasomotor responses to the substitute stimuli. A group of 3 subjects was first tested with the light-vocal stimulus, with the light stimulus, and with the vocal stimulus. This was followed by 40 repetitions of the cold stimulus alone. Then the tests were repeated. Tables 1 and 2 show the essential features of the procedure.

9. *Results of Control Tests with the Light Stimulus.*—(Experiment A, Procedure 1.) As previously described, control subjects were

tested with the light in 6 sessions, covering a period of 9 days, for the purpose of determining the relative frequency of dilation-responses and of constriction-responses in unconditioned subjects.[9] An important consideration was the possibility that repeated testing in itself might produce response increment (sensitization), or decrement (adaptation).

Table 3 gives the results of these tests, in terms of the combined data of the 3 subjects. In the first row of the table we find that of the 60 tests given in the 1st control sessions, 17 percent were without

TABLE 3

VASOMOTOR RESPONSES TO LIGHT IN CONTROL TESTS
Procedure 1; 3 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
1st Control.....	1st	60	17	60	23	1 : 0.4
2nd Control.....	2nd	55	24	49	27	1 : 0.6
3rd Control.....	3rd	55	26	47	27	1 : 0.6
4th Control.....	4th	58	21	48	31	1 : 0.6
5th Control.....	5th	57	35	39	26	1 : 0.7
6th Control.....	9th	55	31	36	33	1 : 0.9

response, 60 percent yielded dilation, 23 percent yielded constriction. The ratio of dilation to constriction was 1 : 0.4. Data of the subsequent control sessions are similarly presented in successive rows of the table.[10]

The percentages of Column V reveal that a *decrease* occurred in the frequency of dilation in the successive sessions, whereas those of Column VI show a contrary tendency, a moderate and irregular *increase* in the frequency of constriction. The resulting change in the

[9] Two measures are commonly employed to represent the extent of conditioning: (1) the magnitude of conditioned responses, (2) the relative frequency of conditioned responses. We chose to use the latter measure, since it seemed to be the more reliable index to the significant changes, as well as the simpler measure to determine.

[10] The data of Table 3 disclose the characteristic vasomotor activity described in Section 5. Only 17 percent of the tests of the 1st control sessions were without response, and in subsequent sessions the tests without response did not exceed 35 percent of the total observations (Column IV). In other words, responses of dilation and of constriction combined occurred in from 65 percent to 83 percent of tests.

For the sake of convenience these changes are referred to as 'vasomotor responses to light,' but as a matter of fact, an indeterminate complex of activities was involved. The proportionate influence of the light in this complex is unknown, but that fact does not invalidate the findings, for upon the reasonable assumption that chance factors (*i.e.*, those not occasioned by substitute and original stimuli) were evenly distributed among the pre-conditioning sessions and the post-conditioning sessions, we have simply to obtain the differences between these two sets of data in order to appraise the influence of conditioning.

ratios of dilation to constriction was from 1 : 0.4 in the 1st control session to 1 : 0.9 in the 6th control.

10. *Results of Pre-conditioning and Post-conditioning Tests with the Light Stimulus.*—(Experiment A, Procedures 2 and 3.) Table 4 presents a summary of the results of pairing light and cold. The data of 5 subjects are combined in the values of this table. Three of these subjects received 20 conditioning combinations; 2 received 40 combinations. Differences in relation to the two procedures were negligible and accordingly all results were combined.

TABLE 4

VASOMOTOR RESPONSES TO LIGHT IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS

Procedures 2 and 3; 5 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
Pre-conditioning.....	1st	96	22	43	35	1 : 0.8
Conditioning *	2nd	—	—	—	—	—
1st Post-conditioning..	3rd	88	22	36	42	1 : 1.2
2nd Post-conditioning..	4th	104	19	40	41	1 : 1.0
3rd Post-conditioning..	5th	100	22	32	46	1 : 1.4
4th Post-conditioning..	9th	93	26	31	43	1 : 1.4

* Three subjects received 20 conditioning combinations of light and cold; and 2 subjects received 40 conditioning combinations. Data of both groups are combined in this table, since differences in results were negligible. The post-conditioning sessions of the 40 combination subjects occurred on the 4th, 5th, 6th and 9th days.

In the first row of Table 4 we find the data of the pre-conditioning tests. Of 96 tests with the light, 22 percent were without a vasomotor response; 43 percent yielded dilation; 35 percent, constriction. The ratio of dilation to constriction was 1 : 0.8.

In the 1st post-conditioning sessions, given the day following the completion of training, there were 88 tests, of which 22 percent were without response; 36 percent were accompanied by dilation; 42 percent, by constriction. The ratio of dilation to constriction was 1 : 1.2. The results of subsequent tests were not greatly dissimilar, as can be readily seen in the table.

A comparison of the percentages of dilation in the post-conditioning sessions with the pre-conditioning percentage (Column V) reveals a *decrease* in frequency of dilation after conditioning. Conversely, frequency of constriction *increased* (Column VI). This was according to expectation, since cold, and consequent constriction, accompanied the light during training. But the fact that similar changes occurred

in the case of the control subjects (Table 3) raised a doubt as to the role of conditioning.

In order to determine whether there was any significant association between training with paired stimuli and the response-frequencies the chi square test was employed. In Table 5 are given the *observed* frequencies of responses in the pre-conditioning tests and in the post-conditioning tests, together with the *theoretical*, or chance, fre-

TABLE 5

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT (AS OBSERVED IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND *P*

Procedures 2 and 3

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
Pre-conditioning				
(Observed frequency)	21	41	34	96
(Theoretical frequency)	(21.2)	(34.9)	(39.9)	
Post-conditioning				
(Observed frequency)	85	134	166	385
(Theoretical frequency)	(84.8)	(140.1)	(160.1)	
Total	106	175	200	481

$\chi^2 = 2.42$ $P = 0.30$

quencies. Of the pre-conditioning tests, 21 were without response, 41 yielded dilation, and 34 yielded constriction. The corresponding theoretical frequencies (given in parentheses) are: 21.2, 34.9, and 39.9. The post-conditioning frequencies were: 85 without response, 134 dilations, 166 constrictions. The corresponding theoretical frequencies are 84.8, 140.1, and 160.1. The theoretical values are those expected on the hypothesis that there is no association between training with the paired stimuli and the response-frequencies. They are obtained by distributing the cell frequencies in the same proportions as the marginal totals. (See Fisher, **2**, pp. 80–111.)

The observed frequencies of the post-conditioning tests show less dilation and more constriction than chance would allow. However, the chi square is only 2.42, and the corresponding value of *P* is 0.30. This means that the probability is 30 in 100 of getting on random sampling a chi square value as great as, or greater than, the one secured. Thus, the deviations from the theoretical values fall short of significance. This suggests the conclusion that the frequency of response is not related to the training.

This conclusion receives support from the chi square test applied to the control data of Table 3. As previously noted, this table shows a decrease in frequency of dilation in successive sessions, and a contrary tendency in the case of constriction. Comparing the frequencies of the 1st and 2nd control sessions (combined for the purpose of gaining an adequate sample) with those of the 3rd to 6th control sessions inclusive, we obtain a chi square of 4.87, and a corresponding *P* value of approximately 0.09. This falls short of the usual minimum level of significance (0.05), but approaches closer to significance than does the *P* of the conditioned subjects, which is 0.30. In other words, the evidence for a significant association between training and response-frequencies is better in the case of the subjects simply tested repeatedly than in the case of the conditioned subjects.

TABLE 6

VASOMOTOR RESPONSES TO IMAGERY IN CONTROL TESTS
Procedure 1; 3 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
1st Control.....	1st	20	30	35	35	1 : 1.0
2nd Control.....	2nd	20	30	35	35	1 : 1.0
3rd Control.....	3rd	30	37	13	50	1 : 3.8
4th Control.....	4th	40	25	50	25	1 : 0.5
5th Control.....	5th	42	29	50	21	1 : 0.4
6th Control.....	9th	55	38	26	36	1 : 1.4

An examination of the data of each individual subject likewise failed to reveal any clearly positive evidence of conditioning.

11. *Results of Control Tests with Imagery.*—(Experiment A, Procedure 1.) As previously described (Section 6), tests for the effects of imagery were regularly interspersed with presentations of the light itself. Table 6 gives the results of tests of imagery in unconditioned subjects in terms of the combined data of the 3 subjects. No consistent trends are discernible, and the results are decidedly erratic. Percentages of dilation range from 13 to 50; those of constriction, from 21 to 50.

A comparison of the ratios of dilation to constriction of Table 3 (Column VII) with those of Table 6 indicates clearly the consistency of responses to the light stimulus itself, as contrasted with the irregularity prevailing when the subject attempted to revive the stimulus in imagery.

12. *Results of Pre-conditioning and Post-conditioning Tests with Imagery.*—(Experiment A, Procedures 2 and 3.) Table 7 summarizes

the results of tests with imagery, before and after the pairing of light and cold. The most marked differences in the post-conditioning values, as compared with the pre-conditioning, were found in the 1st sessions following conditioning where, out of 80 tests, 12 percent yielded dilation, and 58 percent yielded constriction. The ratio of dilation to constriction was 1 : 4.8. This shift in the direction of dominance of constriction following the conditioning suggests a successful issue of the training. However, this degree of dominance was not present in subsequent sessions. If conditioning did succeed the

TABLE 7

VASOMOTOR RESPONSES TO IMAGERY IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS

Procedures 2 and 3; 5 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
Pre-conditioning.....	1st	100	30	24	46	1 : 1.9
Conditioning *.....	2nd	—	—	—	—	—
1st Post-conditioning..	3rd	80	30	12	58	1 : 4.8
2nd Post-conditioning..	4th	100	31	23	46	1 : 2.0
3rd Post-conditioning..	5th	80	29	26	45	1 : 1.7
4th Post-conditioning..	9th	75	15	24	61	1 : 2.5

* Three subjects received 20 conditioning combinations of light and cold; and 2 subjects received 40 conditioning combinations. Data of both groups are combined in this table, since differences in results were negligible. The post-conditioning sessions of the 40 combination subjects occurred on the 4th, 5th, 6th and 9th days.

results were short-lived. Further doubt concerning the significance of this ratio arises from the fact that one of the ratios of dilation to constriction occurring in control subjects was nearly as favorable to the conditioning hypothesis. (See Table 6, 3rd control session, with a ratio of 1 : 3.8.)

The data of Table 7 give a chi square of 1.08, which corresponds to a P of 0.60, approximately. This strongly indicates a lack of association between training with the combined light and cold and the frequencies of responses occurring during tests with imagery. Similarly, the data of Table 6, when grouped with the results of the 1st and 2nd control sessions in one row of cells and those of the 4th to 6th control sessions in the other row of cells, yield a chi square of 0.12, and a P of 0.95, approximately.

The results of the individual subjects were studied for positive effects of conditioning, but nothing approaching clear evidence could be discovered.

TABLE 8

VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI IN CONTROL TESTS *

Procedure 4; 3 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
1st Control.....	1st	90	42	25	33	1 : 1.3
2nd Control....	2nd	95	40	23	37	1 : 1.6
3rd Control.....	3rd	90	29	30	41	1 : 1.4
4th Control.....	4th	85	39	29	32	1 : 1.1
5th Control.....	5th	90	41	16	43	1 : 2.7
6th Control.....	8th	90	29	33	38	1 : 1.2

* One-third of the tests of each subject involved the compound light-vocal stimulus; one-third, the light alone; one-third, the vocal activity alone. The results of all tests are combined in this table.

13. *Results of Control Tests with the Light and Vocal Stimuli.*— (Experiment B, Procedure 4.) In these tests the subject responded to the stimulus vocally as well as visually. He whispered the word 'crosses' while looking at the light. In all sessions, tests were made with this compound light-vocal stimulus, with the light alone, and with the vocal stimulus alone. Tests were evenly distributed in number among the three conditions. The procedure has been described in Sections 4 and 6.

The data of 3 subjects are presented in Table 8. The tests gave fairly regular results from day to day, as shown by the percentages of

TABLE 9

VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS *

20 Conditioning Combinations

Procedure 5; 3 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
Pre-conditioning.....	1st	90	30	38	32	1 : 0.8
Conditioning.....	2nd	—	—	—	—	—
1st Post-conditioning..	3rd	90	36	34	30	1 : 0.9
2nd Post-conditioning..	4th	90	35	33	32	1 : 1.0
3rd Post-conditioning..	5th	95	30	27	43	1 : 1.6
4th Post-conditioning..	8th	90	30	33	37	1 : 1.1

* One-third of the tests of each subject involved the compound light-vocal stimulus; one-third, the light alone; one-third, the vocal activity alone. The results of all tests are combined in this table.

Columns IV, V, and VI. The ratios of Column VII reveal a fairly consistent predominance of constriction.

14. *Results of Pre-conditioning and Post-conditioning Tests with the Light and Vocal Stimuli.*—(Experiment B, Procedures 5 and 6.) Three subjects were put through a 20 conditioning combination routine. No obvious evidence of conditioning was found in these subjects, as is shown by the data of Table 9. The values for all sessions remained much the same, save for the increased frequency of constriction, and decreased dilation, in the 3rd post-conditioning sessions.

TABLE 10

VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS *

40 Conditioning Combinations

Procedure 6; 5 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
Pre-conditioning.....	1st	155	42	24	34	1 : 1.4
Conditioning.....	2nd †	—	—	—	—	—
Conditioning.....	3rd	—	—	—	—	—
1st Post-conditioning..	4th	145	19	19	62	1 : 3.3
2nd Post-conditioning..	5th	145	20	17	63	1 : 3.7
3rd Post-conditioning..	6th	150	19	25	56	1 : 2.2
4th Post-conditioning..	9th	155	26	22	52	1 : 2.4

* One-third of the tests of each subject involved the compound light-vocal stimulus; one-third, the light alone; one-third, the vocal activity alone. The results of all tests are combined in this table.

† 20 conditioning combinations given on 2nd day, and 20 on 3rd day.

Table 10, which summarizes the observations on the 5 subjects receiving *40 conditioning combinations*, exhibits a clear contrast to the data of the control subjects (Table 8) and to those of the 20 combination subjects (Table 9). The most significant values of Table 10 are found in Column VI, which shows that 62 percent of tests yielded constriction in the 1st post-conditioning sessions, and 63 percent in the 2nd post-conditioning sessions, as compared with 34 percent in the pre-conditioning sessions. Conforming to this facilitation of constriction there was some decrease in the frequency of dilation in the 1st and 2nd post-conditioning sessions as compared with the pre-conditioning sessions (Column V).

Chi squares were obtained from the data of control subjects and of conditioned subjects. Table 11 gives the response-frequencies as

TABLE 11

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN CONTROL TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND P *

Procedure 4; 3 Subjects

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
1st and 2nd Control				
(Observed frequency)	76	44	65	185
(Theoretical frequency)	(67.8)	(48.0)	(69.2)	
3rd, 4th, 5th, and 6th Control				
(Observed frequency)	122	96	137	355
(Theoretical frequency)	(130.2)	(92.0)	(132.8)	
Total	198	140	202	540

$\chi^2 = 2.38$ $P = 0.30$ (approximately)

* The observed frequencies have been presented, in a different form, in Table 8.

observed in the control tests, with the results of the 1st and 2nd control sessions combined in one row of cells, and those of the 3rd to 6th control sessions in the other row. The chi square is 2.38; the corresponding P is 0.30, approximately. The conclusion to be drawn

TABLE 12

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND P *

20 Conditioning Combinations

Procedure 5; 3 Subjects

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
Pre-conditioning				
(Observed frequency)	27	34	29	90
(Theoretical frequency)	(28.9)	(29.7)	(31.4)	
Post-conditioning				
(Observed frequency)	119	116	130	365
(Theoretical frequency)	(117.1)	(120.3)	(127.6)	
Total	146	150	159	455

$\chi^2 = 1.18$ $P = 0.60$ (approximately)

* The observed frequencies have been presented, in a different form, in Table 9.

is that there is no significant evidence of association between the repetition of stimuli in control sessions and the response-frequencies.

Table 12 presents the frequencies of vasomotor responses to light and vocal stimuli as observed in pre-conditioning tests and in post-conditioning tests of the 20 combination subjects. The chi square is 1.18; the P is 0.60, approximately. Thus there is no significant indication of dependence of response-frequencies on the conditioning procedure.

TABLE 13

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN PRE-CONDITIONING TESTS AND IN POST-CONDITIONING TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND P *

40 Conditioning Combinations

Procedure 6; 5 Subjects

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
Pre-conditioning				
(Observed frequency)	65	37	53	155
(Theoretical frequency)	(39.3)	(33.3)	(82.4)	
Post-conditioning				
(Observed frequency)	125	124	346	595
(Theoretical frequency)	(150.7)	(127.7)	(316.6)	
Total	190	161	399	750

$\chi^2 = 35.05$ $P = < 0.0001$

* The observed frequencies have been presented, in a different form, in Table 10.

In Table 13 the data of the 40 combination subjects are similarly treated. The table shows for the post-conditioning tests an observed frequency of dilation less than the theoretical frequency, and an observed frequency of constriction greater than the theoretical frequency. The chi square for the table is 35.05, and the P is less than 0.0001. Hence the association between training and response-frequencies is highly significant in the case of the subjects who received 40 training combinations.

The contingency tables just examined contain the combined frequencies of the first two control sessions and of the last four control sessions, or of the pre-conditioning sessions and the post-conditioning sessions. In other words, in the tables in question, results from *the same group of subjects*, either control or experimental, are compared at different stages of the experiment. In Table 14, on the other hand, the results of *two different groups of subjects* are compared,

those of the last four control sessions of Procedure 4 with those of the four post-conditioning sessions of Procedure 6 (the 40 conditioning combination procedure). In this table, as in Table 13, among the post-conditioning data the frequency of dilation is less and the frequency of constriction is greater than would occur in a chance distribution. The chi square is 35.68, and the P is less than 0.0001. Thus, the hypothesis of conditioning receives additional support from this comparison.

TABLE 14

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN CONTROL TESTS AND IN POST-CONDITIONING TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND P

40 Conditioning Combinations

Procedures 4 and 6

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
3rd, 4th, 5th, and 6th Control *				
(Observed frequency)	122	96	137	355
(Theoretical frequency)	(92.3)	(82.2)	(180.5)	
Post-conditioning †				
(Observed frequency)	125	124	346	595
(Theoretical frequency)	(154.7)	(137.8)	(302.5)	
Total	247	220	483	950
	$\chi^2 = 35.68$		$P = < 0.0001$	

* Data of last 4 control sessions of Procedure 4.

† Data of 4 post-conditioning sessions of Procedure 6.

The 'light and vocal stimuli' of the tables discussed above were of three kinds: (1) the compound light-vocal stimulus, (2) the light stimulus, and (3) the vocal stimulus. The results of all testing were combined in order to simplify the discussion. However, the results were not uniformly successful with each of these stimuli, as indicated by the following chi squares, derived from comparisons of pre-conditioning and post-conditioning frequencies. For the compound light-vocal stimulus, the chi square is 25.34; P, less than 0.0001. In the case of the light component, the chi square is 12.97; P, less than 0.01. For the vocal component, the chi square is 3.36; P, 0.19, approximately. That the chi square obtained from the light-vocal tests is larger than that from either of the components is not surprising, in view of the fact that this compound stimulus was actually the substitute stimulus, that is, the stimulus combined with the cold. The

fact that the *P* fails to attain the 0.05 level of significance in the case of the vocal data is particularly important because it demonstrates that the superiority of the light-vocal conditioning over the light conditioning (Experiment B compared with Experiment A) was not due to any special conditioning properties of the vocal activity alone.

15. *Individual Results.*—Individual differences are obscured in the combined data which make up the tables so far presented. However, detailed individual results would expand this paper beyond reasonable limits, and would contribute little to the general significance of the experiments.

Some notion of the extent of the individual variations may be obtained from Table 15 which gives the results of each daily session of testing with the light-vocal stimulus in the 5 subjects who were conditioned by 40 combinations of the light-vocal stimulus and the cold. The table includes only the responses to the 10 light-vocal stimuli presented in each session; the results of tests with the component stimuli (light alone and vocal activity alone) are not given.

The principal evidence for conditioning in Table 15 appears in Column V, which gives the number of constriction-responses in the pre-conditioning session, and in each of the post-conditioning sessions. The post-conditioning values were greater than the pre-conditioning in every instance but three (in the 1st and 4th post-conditioning sessions of Subject K, and the 3rd post-conditioning session of Subject U, the number of constriction-responses, 5, was the same as the number before conditioning).

Column VI shows an excess of constriction-responses over dilation-responses in every post-conditioning session.

Generally speaking, the best evidence of conditioning appeared in these tests of the compound light-vocal stimulus.

16. *Results of Control Tests with the Cold Stimulus.*—(Experiment C, Procedure 7.) Having investigated (*a*) the possibility of response modification through repetition of the *substitute stimulus alone*, and (*b*) the possibility of response modification through the repeated dual presentation of the *substitute stimulus* and the *original stimulus*, there remained (*c*) the problem of determining the effects of repetition of the *original stimulus alone.* Specifically, the question was whether repetition of the cold stimulus in itself could increase the frequency of constriction to the light and the vocal stimulus.

Grether (**4**), Grant and Meyer (**3**), and others, have reported the occurrence of 'pseudo-conditioning,' in which results resembling conditioning appeared without the pairing of stimuli. In these instances formerly neutral stimuli elicited responses after the presentation of an intense stimulus. In view of the somewhat traumatic nature of our cold stimulus for some subjects, the possibility of such pseudo-

TABLE 15

VASOMOTOR RESPONSES OF INDIVIDUAL SUBJECTS TO THE LIGHT-VOCAL STIMULUS IN PRE-CONDITIONING AND IN POST-CONDITIONING TESTS *

40 Conditioning Combinations

Procedure 6; 5 Subjects

I Sessions	II Day of Experiment	III Number of Tests Without Response	IV Number of Tests Yielding Dilation	V Number of Tests Yielding Constriction	VI Excess of Constriction over Dilation
Subject I					
Pre-conditioning	1st	8	0	2	2
Conditioning	2nd	—	—	—	—
Conditioning	3rd	—	—	—	—
1st Post-conditioning	4th	3	1	6	5
2nd Post-conditioning	5th	3	0	7	7
3rd Post-conditioning	6th	2	2	6	4
4th Post-conditioning	9th	3	1	6	5
Subject K					
Pre-conditioning	1st	2	3	5	2
Conditioning	2nd	—	—	—	—
Conditioning	3rd	—	—	—	—
1st Post-conditioning	4th	2	3	5	2
2nd Post-conditioning	5th	2	1	7	6
3rd Post-conditioning	6th	1	1	8	7
4th Post-conditioning	9th	1	4	5	1
Subject M					
Pre-conditioning	1st	0	7	3	−4
Conditioning	2nd	—	—	—	—
Conditioning	3rd	—	—	—	—
1st Post-conditioning	4th	1	1	8	7
2nd Post-conditioning	5th	0	0	10	10
3rd Post-conditioning	6th	1	2	7	5
4th Post-conditioning	9th	2	1	7	6
Subject U					
Pre-conditioning	1st	3	2	5	3
Conditioning	2nd	—	—	—	—
Conditioning	3rd	—	—	—	—
1st Post-conditioning	4th	1	3	6	3
2nd Post-conditioning	5th	0	2	8	6
3rd Post-conditioning	6th	2	3	5	2
4th Post-conditioning	9th	0	2	8	6
Subject V					
Pre-conditioning	1st	10	0	0	0
Conditioning	2nd	—	—	—	—
Conditioning	3rd	—	—	—	—
1st Post-conditioning	4th	3	0	7	7
2nd Post-conditioning	5th	2	0	8	8
3rd Post-conditioning	6th	5	0	5	5
4th Post-conditioning	9th	5	1	9	8

* Only tests with light-vocal stimulus included. Tests with light alone, and vocal activity alone, not included.

conditioning had to be considered, and a control procedure was designed for this purpose.

The procedure has been described in Section 8. It was identical with the conditioning routine employed with the light-vocal stimulus (Procedure 6), excepting that the cold stimulus *was not paired* with the substitute stimulus, but was presented alone, through 40 repetitions, 20 in each of 2 successive day's sessions. Three subjects were used.

The results appear in Table 16, which gives the vasomotor responses to light and vocal stimuli in control tests before and after 40

TABLE 16

VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI IN CONTROL TESTS BEFORE AND AFTER 40 REPETITIONS OF COLD STIMULUS *

Procedure 7; 3 Subjects

I Sessions	II Day of Experiment	III Number of Tests	IV Percentage of Tests Without Response	V Percentage of Tests Yielding Dilation	VI Percentage of Tests Yielding Constriction	VII Ratio of Dilation to Constriction
1st Control.....	1st	90	37	33	30	1 : 0.9
20 Repetitions of Cold.	2nd	—	—	—	—	—
20 Repetitions of Cold.	3rd	—	—	—	—	—
2nd Control.....	4th	90	21	39	40	1 : 1.0
3rd Control.....	5th	90	22	39	39	1 : 1.0
4th Control.....	9th	90	31	31	38	1 : 1.2

* One-third of the tests of each subject involved the compound light-vocal stimulus; one-third, the light alone; one-third, the vocal activity alone. The results of all tests are combined in this table.

repetitions of the cold stimulus. The percentages of Columns V and VI of Table 16 show that increased activity, both of dilation and of constriction, occurred in the sessions after cold stimulation.

The frequencies of the 1st control sessions are compared with those of the 2nd, 3rd, and 4th control sessions in Table 17. It will be observed that in the control sessions following the cold stimulations (2nd, 3rd, and 4th sessions), frequencies of dilation and of constriction are slightly larger than chance would allow. The chi square is 5.03, and the P is 0.09, approximately. Thus, the deviation falls a little short of attaining the usual criterion of significance (0.05).

Table 18 compares the results of the tests upon the cold-control subjects with those derived from the 40 conditioning combination subjects. Attention is called to the post-conditioning data where the dilation value is less, and the constriction value is greater, than chance would allow. If the modifications assumed to result from condition-

ing were in fact simply due to the repetition of the cold stimulus, the observed and theoretical frequencies of this table should be closely alike. As a matter of fact the deviation is large, and is significant, as attested by the chi square of 31.72, with the corresponding P of less than 0.0001.

Another approach to the comparison of response-frequencies in the experimental (conditioned) group and the cold-control group is provided by the ratios of dilation to constriction as shown in Table 10 and Table 16. For the conditioned subjects (Table 10) the pre-conditioning ratio was 1 : 1.4; whereas the the post-conditioning

TABLE 17

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN CONTROL TESTS BEFORE AND AFTER 40 REPETITIONS OF COLD STIMULUS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND P *

Procedure 7; 3 Subjects

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
1st Control†				
(Observed frequency)	33	30	27	90
(Theoretical frequency)	(25.0)	(32.0)	(33.0)	
2nd, 3rd, and 4th Control ‡				
(Observed frequency)	67	98	105	270
(Theoretical frequency)	(75.0)	(96.0)	(99.0)	
Total	100	128	132	360
	$\chi^2 = 5.03$		$P = 0.09$ (approximately)	

* The observed frequencies have been presented, in a different form, in Table 16.

† Tests preceding 40 repetitions of cold stimulus.

‡ Tests following 40 repetitions of cold stimulus.

ratios were, 1 : 3.3, 1 : 3.7, 1 : 2.2, and 1 : 2.4. For the control subjects (Table 16), the ratio before cold stimulation was 1 : 0.9; whereas the ratios after cold stimulation were 1 : 1.0, 1 : 1.0, and 1 : 1.2. These figures show that the relative frequency of constriction to the light and vocal stimuli was markedly increased following conditioning, by contrast to the slight increase following cold stimulation. Even this slight increase is of dubious significance in relation to the cold stimulation in view of the fact that a comparable trend was observed in the case of the control subjects who were tested with the light and vocal stimuli alone. (Compare Tables 8 and 16.)

In summary, all the evidence points to the conclusion that the response modifications following the 40 cold stimulations were in no

wise comparable to the changes observed after conditioning. This conclusion further supports the hypothesis of successful conditioning to the light and vocal stimuli.

17. *Conditioning to the Compound Stimulus.*—It has been pointed out that conditioning to the light failed, while conditioning to the light combined with the subject's vocal activity was unquestionably successful. The chi squares given in Section 14 prove that this difference was not due to any superior conditioning readiness of the vocal activity as compared with the light, but rather that it was a function of the compound stimulus itself.

TABLE 18

FREQUENCIES OF VASOMOTOR RESPONSES TO LIGHT AND VOCAL STIMULI (AS OBSERVED IN CONTROL TESTS AFTER 40 REPETITIONS OF COLD STIMULUS AND IN POST-CONDITIONING TESTS) COMPARED WITH THEORETICAL FREQUENCIES; WITH CHI SQUARE AND *P*

Procedures 7 and 6

I Sessions	II Number of Tests Without Response	III Number of Tests Yielding Dilation	IV Number of Tests Yielding Constriction	V Total
2nd, 3rd, and 4th Control *				
(Observed frequency)	67	98	105	270
(Theoretical frequency)	(59.9)	(69.3)	(140.8)	
Post-conditioning †				
(Observed frequency)	125	124	346	595
(Theoretical frequency)	(132.1)	(152.7)	(310.2)	
Total	192	222	451	865
	$\chi^2 = 31.72$		$P = < 0.0001$	

* Tests following 40 repetitions of cold stimulus (Procedure 7).

† Tests following 40 combinations of cold stimulus and light-vocal stimulus (4 post-conditioning sessions of Procedure 6).

The facilitation of a response through the summation of stimuli is a familiar phenomenon. Summation in the form of concurrent stimulation of two (or more) sensory modalities has been found to reduce reaction time (**13**); to enhance visual discrimination (**5**), and cutaneous discrimination (**8**); and to facilitate conditioning (**6**). A common principle may be involved in all such cases.

But almost certainly there was more involved than the mere summation of stimuli in the case of the present experiment. Task-set, attitude, affect, and other complex variables were probably operating, but to what extent remains unknown. In this connection, Razran (**11**) has provided some interesting evidence on the role of task-sets or attitudes in conditioning with simple and compound stimuli. He

found that the compound stimuli were the more effective conditioners in the case of one task-set, whereas the components of the compound possessed an advantage in the case of another task-set.

In the present experiment different task-sets might well have exercised an influence upon conditioning. Looking at a light while pronouncing a word at a certain rate and intensity could be, in terms of task-set, a very different thing from simply looking at the light.

18. *Ideo-Motor Action.*—As described in Section 12, the tests with imagery of the light, made after combining the light with the cold, failed to provide any reliable evidence of a learned connection between the imagery and the vasoconstriction. However, some evidence pointing to this possibility was obtained in the course of a brief investigation of the correlation between thought processes and vasomotor activity.

The skin temperature of one subject (L. B.) was measured during the recall of specific past experiences involving extremes of cold and warmth.[11] The recall reached back several years to a period when the subject worked as a stoker on a ship. A typical cold experience was: "Cold drops of water running down my back." Among the hot experiences was: "Steam escaping from a valve and blowing against my hand." These experiences were apparently revived as imagery, and only later formulated in words. Out of 5 observations involving cold imagery, *a fall in temperature occurred in every case.* The mean change in temperature at the point of application of the thermopile (the thenar eminence) was 0.4° C. (circa). The subject's efforts at recall extended through about 1 minute in each case. The delay between the indicated beginning of recall and initial drop in temperature ranged from 10 to 20 seconds, and the fall was displaced by a rise within 1 to 30 seconds after the reported termination of the recall. Out of 5 observations with hot imagery, a rise occurred in 3 cases, a slight fall in 1 case, and no response in the remaining case. The mean rise in temperature was 0.4° C.

In addition to these trials involving the recall of specific experiences, the subject attempted to lower the skin temperature by 'willing.' He suggested this himself, saying that he felt he could lower the temperature whenever he wanted to do so. However, 5 such attempts failed to have any effect on the temperature curve. The subject described his effort in these words: "I thought of the temperature going down, of the arm being cold." Apparently imagery was not involved in these trials, by contrast with the earlier efforts.

[11] L. B. was a subject in the earlier experiment in which vasoconstriction was conditioned to the sound of a buzzer and to a vocal stimulus.

Six other subjects were observed, during one session each, for the vasomotor effects of 'temperature imagery.' [12] In the case of 3 subjects there were no reliable differences between control and experimental periods. With the remaining 3 subjects, however, the results seemed to indicate some relationship between imagery and responses, as shown by the following data:

Subject P. E.	10 cold images:	30 percent rises, 50 percent falls, 20 percent no change.
	12 hot images:	59 percent rises, 8 percent falls, 33 percent no change.
Subject T. H.	10 cold images:	20 percent rises, 50 percent falls, 30 percent no change.
	10 hot images:	50 percent rises, 20 percent falls, 30 percent no change.
Subject L. H.	6 hot images:	67 percent rises, 0 percent falls, 33 percent no change.

This evidence is not sufficient to support any general conclusions, but it definitely suggests that the recall of experiences involving extremes of cold and heat was sufficient, in some cases, to produce the vasomotor adaptation appropriate to the original situation. One is reminded of William James's dictum concerning ideo-motor action: "The fact is that there is no sort of consciousness whatever, be it sensation, feeling, or idea, which does not directly and of itself tend to discharge into some motor effect" (7, p. 170).

19. *Degree of Conditioning.*—The present study was not designed to obtain the maximum degree of conditioning. In a few instances 100 percent of trials yielded vasoconstriction after conditioning, and there is reason to believe that such a degree of conditioning could be attained more frequently with certain modifications of method. An increase in the number of conditioning combinations would be expected to enhance the conditioning. Other kinds of stimuli, particularly of the auditory modality, might be more successful than the visual and vocal stimuli. The fact that our subjects were seldom in an alert state of attention may have influenced the results. Sitting in a relaxed condition for over an hour, in a quiet, warm, and dimly illuminated room was obviously conducive to drowsiness. The task of looking steadily at a light, of monotonously repeating the same word, or of holding the eyes closed while attempting to produce imagery, further contributed to the subject's somnolence. In fact, one subject came to the conclusion that our purpose was hypnotism.

In the study published prior to this one, successful conditioning of vasoconstriction to a light stimulus was reported in 4 subjects. In addition, it was found that imagery of the light was accompanied by changes comparable to the conditioned ones in 3 out of 4 subjects. These results were presented in terms of the percentages of dilation and of constriction occurring in tests of individual subjects. Chi squares have since been computed, based on the frequencies of re-

[12] None of these 6 subjects was used in the experiment proper. They were tested only for the effects of imagery, and no attempt was made to condition them.

sponses in pre-conditioning and post-conditioning tests. For the light stimulus the chi square is 19.12, and the *P* is less than 0.0001. For the imagery the chi square is 7.94, and the *P* is 0.02.

It is not known why success attended the previous effort and not the present one. The method of conditioning was nearly the same in both investigations. A difference, however, was that the training was more distributed in the earlier study, in which there were usually three conditioning sessions, with testing sessions interspersed between each one. Conceivably this favored conditioning.

20. *Summary of Procedures.*—Vasoconstriction was produced by stimulating one hand with cold water. The skin temperature changes of the other hand were measured by means of a thermopile and galvanometer, and these changes were taken as indices of vasomotor responses. In Experiment A the substitute stimulus was a light. The subject's vocal activity was joined with the light to provide the substitute stimulus of Experiment B. The substitute stimulus was paired with cold water to produce conditioning. Tests of the substitute stimulus were made before and after conditioning, and extensive tests were carried out upon control subjects as well. Twenty-two men acted as subjects; 9 in the control procedures, and 13 in the conditioning procedures.

The procedures were as follows:[13]

(1) Vasomotor responses to the light, and to imagery of the light, were observed in 3 subjects, on 6 days each. (Experiment A, Procedure 1.)

(2) Three subjects were trained by presenting the light and the cold together, 20 times in each case. Tests for vasomotor responses were made with the light, and with imagery of the light, on the day preceding the conditioning session, and on each of 4 days after the conditioning. (Experiment A, Procedure 2.)

(3) Two subjects each received 40 combinations of the light and the cold. Tests for vasomotor responses were made with the light, and with imagery of the light, on the day preceding the first conditioning session, and on each of 4 days after the second conditioning session. (Experiment A, Procedure 3.)

(4) Vasomotor responses to the light and the vocal activity together (light-vocal stimulus), as well as to the light alone, and the vocal activity alone, were observed in 3 subjects, on 6 days each. (Experiment B, Procedure 4.)

(5) Three subjects each received 20 combinations of the light-vocal stimulus and the cold. Tests for vasomotor responses were made with the light-vocal stimulus (and with each component of this

[13] These procedures are outlined in Tables 1 and 2.

compound stimulus) on the day preceding the conditioning session, and on each of 4 days after the conditioning. (Experiment B, Procedure 5.)

(6) Five subjects each received 40 combinations of the light-vocal stimulus and the cold. Tests were made, as described in (5) above, on the day preceding the first conditioning session, and on each of 4 days after the second conditioning session. (Experiment B, Procedure 6.)

(7) Three subjects each received 40 cold stimulations, but no conditioning combinations. Tests were made, as described in (5) above, on the day preceding the first cold session, and on each of 3 days after the last cold session. (Experiment C, Procedure 7.)

(8) The influence of imagery upon vasomotor activity was investigated in 7 subjects who were not conditioned experimentally, but who recalled life experiences involving extremes of temperature.

21. *Conclusions.*—Conditioned vasoconstriction to the *compound light-vocal* stimulus occurred in the 5 subjects who received 40 training combinations. Conditioning failed in the subjects who were given 20 training combinations.

Control experiments showed that the essential aspect of the training consisted in the dual stimulation, and not in the repetition of the light-vocal stimulus alone, nor in the repetition of the cold stimulus alone.

Attempts to condition vasoconstriction to the *simple light stimulus* (*i.e.*, without vocal activity) were unsuccessful after 40 training combinations. It is not known why joining vocal activity to the light stimulus was critical to the conditioning. The data of the experiment are opposed to the hypothesis that the simple vocal activity possessed any superiority over the light in ease of conditioning. It is possible that the compound stimulus had some advantage over the single stimulus in terms of task-set, or attitude; perhaps some basic neural principle of stimulus-summation was involved.

There was no reliable evidence of conditioned vasoconstriction occurring with imagery of the light, but this was not significant since tests with the light itself produced negative results in the same experiment. However, tests upon subjects not participating in the experimental conditioning showed that in some cases the recall of past experiences involving extremes of warmth was correlated with vasodilation, while the recall of cold experiences was correlated with vasoconstriction.

(Manuscript received May 12, 1941)

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TIME RELATIONS IN THE EFFECT OF A SURROUNDING FIELD ON FOVEAL CRITICAL FLICKER FREQUENCY [1]

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It has come to be recognized in recent years that the condition of the visual field surrounding the point of regard can have important influences on the efficiency of any visual process. Many applications of empirical findings of this nature have been made by illuminating engineers in industrial situations (**14**). The same general principles have also been applied to the problem of reading and student studying.

Approaches have been made from several directions on the theoretical problem of accounting for the various effects produced when a function is tested at one point in the visual field with the concomitant illumination of other regions. The most elementary, yet sometimes unrecognized explanation of such effects is given in terms of scattered light. The optic media are by no means perfectly transparent and the iris and choroid are only relatively opaque. The retina in even an emmetropic eye will therefore receive a considerable amount of non-imaged illumination. This will always operate to decrease the efficiency of any discriminative function. Bartley and Fry (**2**) have developed an indirect method of measuring the scattering of light around a small bright image and they find a gradient whose decrease can be followed for several degrees. Taking such an investigation into consideration along with the physical optics of the eye, one marvels that our visual mechanism is able to function as well as it does.

A second mechanism of interaction is comprised of the neural connections in the retina. The anatomical basis for such a mechanism is clear-cut and has been closely correlated with sensation data (**10, 11, 9, 3, 13**). The spatial limits of these effects (the width of a dark region across which one illuminated area can influence the function of a second tested area) is usually found to be a degree or less in the foveal region and three degrees in the periphery. The greater part of the data shows facilitative and summative effects but inhibitory relationships have been demonstrated by Fry (**8**).

The anatomy of the optic pathways in the central nervous system is complex enough to lead us to expect manifold varieties of inter-

[1] This research was made possible by a grant from the Penrose Fund of the American Philosophical Society, and was assisted by the Faculty Research Fund of Rhode Island State College, where the experimental work was done.

action in the lateral geniculate bodies and the cortex. A number of phenomena, apparently dependent on such mechanisms, have yet to be explained in detail. Within the limited field usually called 'sensation,' Sherrington's early studies (**20**) on binocular flicker, and the experiences of binocular color contrast and binocular color mixture, are examples. Bartley's work (**1**) on rabbits, showing the dependence of cortical reaction time on the size of the retinal area stimulated, points to the complexity to be found even at that level of encephalization.

This report will be chiefly concerned with another interaction mechanism of an altogether different sort. It was first suggested by Cobb (**5**) and has been developed by Ross (**17, 18**) as the 'V-substance' hypothesis. It is an addition to the generally accepted picture of the photosensory process as a reversible reaction whose equilibrium state is a function of the intensity of the illumination. The hypothesis can be given the following statement. As a result of the initial photosensory reaction there is produced in the retina, from the retinal tissues, from the blood, or perhaps from some more distant source, a material called 'V-substance.' This material is freely diffusible in the retina, and it acts to hasten the resynthesis of the photosensory substance. That is, it tends to push the reversible photosensory reaction in the direction of reconstitution. Because of its diffusibility, the amount of 'V-substance' acting on any point in the retina tends to be a function of the total light flux impinging on the retina as a whole. Changes in the amount of 'V-substance' could therefore be produced by varying either the intensity or the area of retinal illumination. Its presence would operate to improve the efficiency of any visual function except the perception of the absolute threshold. Analogues of this mechanism might be the interrelated secretions of the endocrine system, and the production of histamine in the 'triple-response' of the skin.

There is a considerable amount of data which can be explained by this hypothesis if the known effects of scattered light be taken also into account. A number of studies (**6, 4, 16, 15**) have shown that when the brightness of the rest of the field of view is increased, the foveal functions of brightness discrimination, acuity, and the perception of flicker improve, up to a point where the test object and the surrounding field are of about equal brightness. When the brightness of the surrounding field is increased beyond this point foveal function becomes rapidly poorer, a result to be expected from scattered light. The increasing efficiency of function fits the expectations of the hypothesis but it might be explained with equal ease as a neural interaction phenomenon in the retina. That is, although the whole field was illuminated, the only effective part of it may have

been the region immediately surrounding the test area. Such data as these, then, are in consonance with, but not critical evidence for, the 'V-substance' hypothesis.

Results of a similar sort have been reported when the size of the surrounding field is varied. Hecht and Smith (**12**) have shown that the size of the surrounding field has important influences upon the relation between illumination and critical flicker frequency. The writer (**7**) has reported increases in acuity when the diameter of a circular area around a two-degree test object was increased from seven to forty-two degrees. It is out of the question to account for such large areal changes on the basis of neural interaction in the retina but the possibility is still open of explaining them as the effect of some integrative process in the higher centers. The problem of determining whether the 'V-substance' hypothesis has any explanatory value for interaction phenomena remains, then, that of distinguishing between the effects which might be the result of central nervous system activity and those which could depend upon a diffusion process of physiological products in the retina.

A situation which ought to be critical for such a distinction would be one in which time was the significant variable. When a surrounding field influences a foveal function we should expect any neural effect to reach its maximum immediately, and thereafter, to remain constant or decrease. On the other hand, if the 'V-substance' hypothesis holds, we should expect any change in a tested function to show a gradual increase lasting over a period of minutes. Such a period would be necessary before the whole eye could reach the new equilibrium imposed by the presence of 'V-substance.'

The present investigation is concerned with an attempt to follow the time course of the influence of the surrounding field. The situation was one in which the critical flicker frequency (hereinafter, the *c.f.f.*) at the fovea was measured continuously in the alternate presence and absence of an illuminated surrounding field. The important experimental variable was the length of the interval of alternation. A standard period of continous measurement, 16 minutes long, was employed. Liminal judgments were made by the method of limits at a rate of approximately 20 seconds per reading. In any 16-minute period only one alternation interval was used. In various periods the interval during which the surrounds were present and absent varied from 20 seconds to 4 minutes. The 48 readings taken during a 16-minute period were averaged in two groups: the 24 taken with the surrounds, and the 24 taken without. The 'V-substance' hypothesis would predict that the difference between these averages would increase as the length of the alternation interval increased. For example, we should expect the difference between average c.f.f. with

and without surrounds to be less when alternate liminal measures are secured with the surrounds illumination on and off, than when twelve liminal readings are taken at a time, with the surrounds illumination on and off. Both from neural interaction and from 'V-substance' we should expect the c.f.f. to be higher with than without surrounds, but if the maintenance of either condition makes for a further separation of the two limens something in addition to the neural factor must be involved.

Attention should be called to an assumption implicit in the foregoing. The effect of 'V-substance' is assumed to take place at a rate characterized by negative acceleration, and to dissipate in the same fashion. Such a property would be expected from the nature of the physiological process we have postulated. If it were not so, and if the increase and decrease of the 'V-substance' effect were represented by straight lines, then the pairs of averages referred to above would differ by the same amount regardless of the length of the alternation interval.

Apparatus and Procedure

The apparatus is diagrammed in Fig. 1. The primary light source (L_1) was a 50-watt projection lamp run on 12 volts, d.c., at a carefully controlled amperage. The beam from the projector was cut by a sectored disc (*SD*) with two open quadrants. This disc was on one end of a motor shaft (*M*) the other end of which was attached to a Type A Jagabi tachometer (*T*)

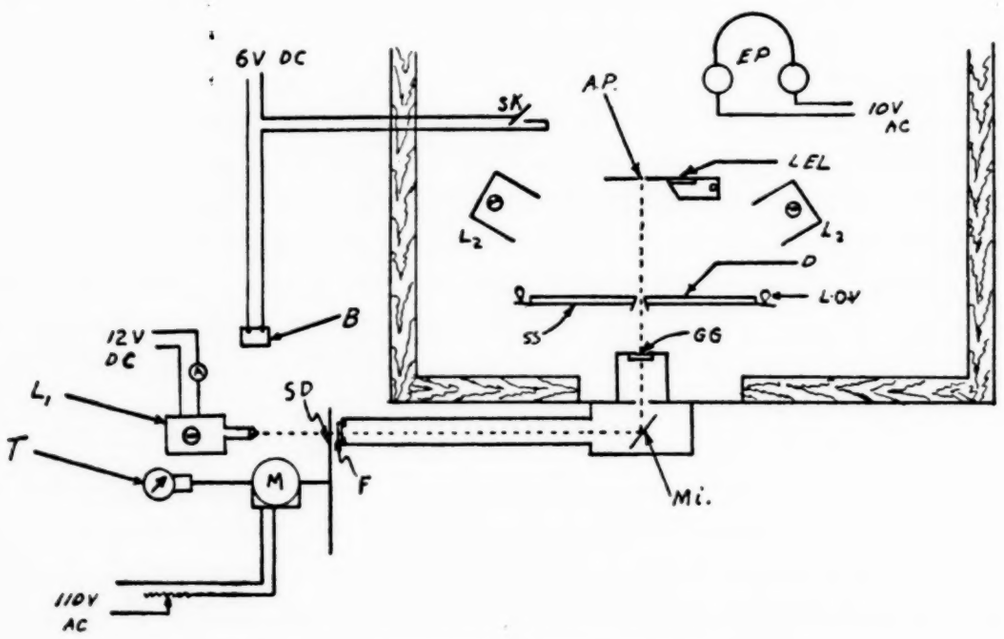

Fig. 1. Apparatus. Described in text.

by a rubber coupling. The speed of the motor was controlled by a rheostat in series with it. Beyond the sectored disc the light beam from the projector passed through a Wratten filter (*F*) and was reflected by a mirror (*Mi*) into a dark-room where it fell on a ground glass plate (*GG*). With his right eye the subject looked through a 2 mm artificial pupil (*AP*) at the ground glass screen which was the test object. To maintain his left eye at a constant state of adaptation

there was a field close in front of it (*LEL*) having a brightness a little above the cone threshold. This field was a piece of ground glass illuminated from behind by a small part of the light from a flashlight bulb.

The test object was seen through a hole in the surrounds screen (*SS*). The screen was covered with black velvet and had a reflectance coefficient of less than .001. The experimental surrounding fields were placed against this screen. They were of two shapes, as pictured in Figs. 2*a* and 2*b*. Figure 2*a* shows a disc in whose center was a hole accurately machined to

a *b* *c*

FIG. 2. Appearance of the stimulus fields. Described in text.

subtend 2° at the subject's eye. This hole served to bound the test object. The outside diameter of the disc was 42°. The annulus of Fig. 2*b* had outside and inside diameters of 42° and 18°. When this annulus was in place a 2° view of the test object was provided by a special aperture in the black screen. Thus the annulus was separated from the test object by an 8° dark space. Figure 2*c* shows the appearance of the stimulus field when the illumination of the surrounds was turned off. The four points of light represented in the views of Fig. 2, and as *LOV* in Fig. 1, were the 'limit-of-view' lights. They were flashlight bulbs run at a voltage barely sufficient to make their filaments glow. Placed one degree beyond the edge of the surrounding fields, they served, with the artificial pupil, to control the head and eye position of the subject. He was instructed to maintain a head position which would keep these lights just at the margin of the field of view permitted by the artificial pupil. Taking and holding this position required some practice, but before the taking of these data the subjects had served some twenty hours in the experimental situation and were well habituated to the procedure. Assuming this position centered the optic axis on the artificial pupil—a matter of some importance (21)—and also controlled the distance of the eye from the test field. This procedure made unnecessary the use of a wax bite which would have been uncomfortable over a long experimental session.

The surrounding fields were illuminated by a set of lamps, two of which are shown as L_2 in Fig. 1. These lamps were provided with ground glass screens and metal diaphragms to permit accurate adjustment of the illumination. They were controlled by a switch on the experimenter's table. Two levels of brightness of the surrounding field were used, 103 c p sq m and 1030 c p sq m. The test object had one brightness throughout the experiment—5.8 c p sq m.

The subject wore earphones (*EP*) to mask the sound of the motor except when an electric fan was running in the dark-room, which served the same purpose. A key (*SK*) was conveniently placed on the supporting pillar of the headrest, with which the subject could give buzzer (*B*) signals to the experimenter.

The experimental procedure has already been briefly outlined. However, because procedure is so important an element in the control of conditions in a problem such as this, it will be described at some length. The account of one session can serve as a sample. There was one systematic variation among the sessions but most elements were standard. The subject entered the dark room and was allowed five minutes for dark adaptation. At a signal from the experimenter he felt his way into his position in the headrest. The experimenter turned on the limit-of-view lights and the subject adjusted his head position properly with respect to them. The test object light was then turned on. This always appeared flickering. The subject fixated a tiny ink spot at the center of the test object and the surrounds lights were turned on. The subject had been instructed to maintain fixation as constantly as possible on the ink spot, especially when the surrounds lights were on. Introspective reports indicate that the subjects' previous practice in the experimental situation enabled them to do this rather easily.

Immediately the surrounds lights were on, the experimenter speeded up the motor and the subject signalled with his key when the flicker-to-fusion threshold was passed. This first reading in a series of 49 was noted but not recorded in the data. The motor was then speeded up to a rate well above the threshold, and deceleration was started. At the commencement of this deceleration the experimenter gave the subject a 'ready' signal by flicking the limit-of-view lights off and on. The subject reported the passage of the fusion-to-flicker threshold with his key and the experimenter read and recorded the motor speed from the tachometer at that moment. The motor was allowed to slow down well below the threshold and then was speeded up. The 'ready' signal was given, and the threshold was signalled, read and recorded as before. The procedure was continued in this fashion for four minutes, which was time for 12 recorded threshold measures, six of fusion-to-flicker and six of flicker-to-fusion. Without any pause, the surrounds illumination was then turned off and readings were continued for another four minutes, time for 12 measures with a dark surrounding field. Again, without interruption, the surrounds illumination was turned on for 12 more readings in the third four-minute interval. Finally the last twelve readings were made with the surrounds dark.

In this 16-minute period there were secured 48 liminal measures, 24 with the surrounds illuminated and 24 with the surrounds dark. Each group of 24 consisted of 12 flicker-to-fusion and 12 fusion-to-flicker readings. The approach to the limen in the two directions was made at the same rate by adjusting the rheostat so that the rate of acceleration and deceleration of the motor were approximately the same. Each measurement was proceeded by a 'ready' signal, given when the motor speed was 6 to 8 flashes per second away from the last reported threshold in the same direction. This relative consistency was not a source of constant error in determining the threshold because it affected the flicker-to-fusion and fusion-to-flicker thresholds on opposite directions. The subjects were unaware of the systematic character of the preparatory interval. The judgments of the limen themselves were sufficiently variable to produce a considerable amount of variation in the starting point of successive judgments. There was no evidence, in the data or from introspections, indicating that the time lapse between 'ready' signal and approximate threshold was a cue. This method was easier on the experimenter and in other ways more satisfactory than using a pre-arranged chance order of starting points.

Following the first 16 minute period of readings the subject was allowed five minutes of rest and dark adaptation. Then the procedure described was repeated except that the turning on and off of the surrounds illumination occurred every two minutes, instead of four. There was time in each two-minute interval for six measurements. At the end of 16 minutes there were again 48 readings, half of them made with the surrounding field illuminated and half with the surrounding field dark.

Following another 5 minutes of rest and dark adaptation the procedure was gone through a third time with an alternation interval of 1 minute—time for three readings. The only difference in this period was that the twelfth and thirteenth readings and the thirty-sixth and thirty-seventh readings were made with the approach to the limen in the same direction. Such a procedure was necessary in order that there might be equal numbers of 'down' and 'up' readings both with and without the illumination of the surrounding field.

After a brief rest period outside the dark room the subject again dark adapted for five minutes before the final 16-minute period of readings. In this period the surrounding field was illuminated and dark for intervals of twenty seconds, during which one reading was made. As in the previous period, and for the same reason, the twelfth and thirteenth and the thirty-sixth and thirty-seventh readings were made in the same direction.

Such was the procedure for one day's session. On another day the whole procedure of four 16-minute periods of continuous readings was repeated, except that the order in which the alternation intervals were used was reversed; that is, in the first sixteen minute period the alternation interval was 20 seconds and in the last, 4 minutes. In this experiment each of two subjects served in 8 sessions. Both the disc and the annulus were used as surrounds at two illuminations, 103 c p sq m and 1030 c p sq m. Two women college students served as subjects. They were aged 19 and 20; both had visual acuities of 1.75/1.75 or better on the Snellen scale and had normal color vision by the Ishihara test. They were paid by the hour and were naïve with respect to the purpose of the experiment.

As pointed out above, the 48 readings taken in a 16-minute period were divided into two groups, 24 taken with the surrounding field illuminated and 24 with the surrounding field dark. The liminal c.f.f.'s for the two conditions were the averages of each of these two groups. The

reliabilities of the limens were calculated in the following fashion. The average deviation of each set of 12 readings, from flicker to fusion or from fusion to flicker, was calculated. The mean of these two A.D.'s was taken as the A.D. of the limen. This was converted to an S.D. value and the σ_m was calculated from it, taking $N = 24$. This is not the most refined procedure for determining reliability, but the conclusions of this study do not rest upon the size of these measures. They are chiefly significant as showing the order of magnitude of the variability of the data.

Results

The results are presented in the tables, which show the c.f.f.'s for each subject and each condition, with their reliabilities. The mean c.f.f.'s for the four sessions with each surrounds condition and the differences between the pairs of means for each time interval are also presented. No reliabilities are given for the mean values, but some notion of the significance of the differences they represent is available from a consideration of the reliability of the differences between pairs of limens for single sessions. Of the sixteen pairs of limens secured with a 20-second interval, only four were significantly different; *i.e.*, had a critical ratio of three. Eleven of the fourteen differences were significant when the interval was one minute. Fourteen of sixteen and fifteen of sixteen differences were significant with the two minute and four minute intervals, respectively.

There was a slight and inconsistent tendency for the A.D. to be larger with the disc as surrounds than with the annulus. The A.D.'s were approximately the same with and without the surrounds, and with the higher and lower illumination of the surrounds. The two subjects differed considerably in the precision of their limens. One subject (B) had A.D.'s ranging from .48 to 2.04 flashes per second with an average of 1.04. The other's ranged from .34 to .77 flashes per second with an average of .56.

TABLE I

Relation of Critical Flicker Frequency to Length of Alternation Interval

Surrounding field: Annulus, with a brightness of 103 c p sq m

Subj.	First Int.	20 seconds				1 minute				2 minutes				4 minutes			
		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark	
		c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m
B	4′	25.65	.19	24.40	.21	25.67	.17	24.25	.18	25.72	.13	24.28	.19	27.83	.20	25.28	.18
B	20″	27.82	.21	26.64	.25	28.18	.18	26.99	.26	27.54	.30	25.29	.22	26.99	.21	24.54	.29
M	4′	22.01	.14	21.75	.10	22.19	.15	21.99	.11	22.75	.11	22.10	.10	23.42	.15	22.60	.15
M	20″	23.10	.12	22.86	.09	23.14	.14	22.26	.13	23.26	.16	22.21	.14	22.72	.09	22.01	.14
Ave...		24.64		23.91		24.80		23.87		24.82		23.47		25.24		23.61	
Diff...		.73				.93				1.35				1.63			

TABLE II

RELATION OF CRITICAL FLICKER FREQUENCY TO LENGTH OF ALTERNATION INTERVAL
Surrounding field: Disc, with a brightness of 103 c p sq m

Subj.	First Int.	20 seconds				1 minute				2 minutes				4 minutes			
		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark	
		c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m
B	4′	25.27	.48	25.94	.28	25.49*		25.52*		25.82	.29	24.90	.27	27.48	.28	24.32	.28
B	20″	30.15	.34	27.94	.15	30.72*		28.04*		31.58	.26	28.18	.31	31.37	.27	26.98	.23
M	4′	24.36	.16	23.08	.15	25.31	.20	23.72	.16	26.32	.13	23.72	.15	26.22	.14	24.17	.17
M	20″	23.61	.14	23.51	.20	24.29	.17	23.06	.11	24.03	.17	22.74	.18	23.24	.15	21.99	.12
Ave...		25.85		25.12		26.46		25.09		26.94		24.89		27.08		24.37	
Diff...		.73				1.37				2.05				2.71			

* — Interpolated value.

It will be noted that the data for subject B are incomplete for the one-minute interval in Table II. In order that the other subject's data might be used in securing mean values which would be comparable with those for the other time intervals, the missing limens were interpolated between the 20-second and 2 minute values of the incomplete sessions. A straight line relationship was assumed between the points.

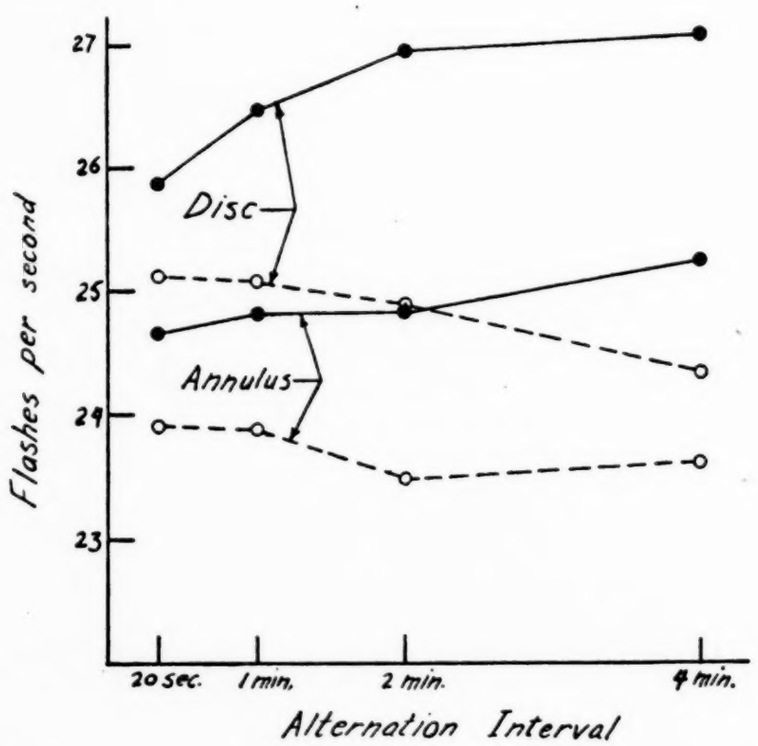

FIG. 3. Influence of alternation interval on critical flicker frequency. Brightness of surrounding field: 103 c p sq m. Brightness of test object: 5.8 c p sq m. Solid lines: surrounding field illuminated. Dashed lines: surrounding field dark.

Close analysis of the tables will show that a considerable 'fatigue' effect was operative in the 1½-hour experimental session. An index of the change in c.f.f. would be a comparison, for all sessions under all conditions, of the means of the first, second, third, and fourth 16-minute periods of each session. The mean values for these periods, in order, are: 26.20, 25.58, 25.30, 25.25. Each of these means is derived from at least 672 liminal measures, equally divided between those taken with and without surrounds, with 103 and 1030 c p sq m brightness of surrounds, and with the disc and annulus as surrounds. The first and last values were derived from equal numbers of measures

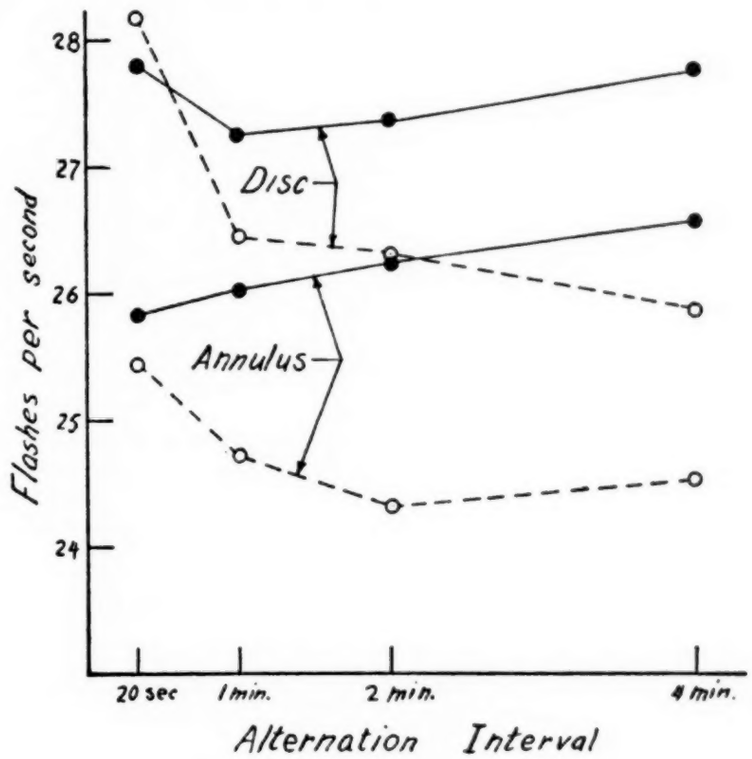

FIG. 4. Influence of alternation interval on critical flicker frequency. Brightness of surrounding field: 1030 c p sq m. Brightness of test object: 5.8 c p sq m. Solid lines: surrounding field illuminated. Dashed lines: surrounding field dark.

taken with the 20-second and four-minute intervals. The second and third were derived from equal numbers of measures taken with the one-minute and two-minute intervals. Correction was made in the calculations for the missing values for subject B noted above. The mean values of the four 16-minute periods show that the decrement was most rapid during the first half hour of work during a session and that the longer rest period introduced between the third and fourth 16-minute work periods, at the end of approximately one hour of work, served very nearly to check the fall in the c.f.f.

The data of Tables I and II are plotted in Fig. 3. The mean c.f.f.'s for each shape of the surrounding field and with that field illuminated and dark are plotted against the length of the alternation

interval. The significant fact to be noted in this graphic representation is that each pair of gradients becomes increasingly separated as the longer intervals are approached. In Fig. 4 the data of Tables III and IV are plotted in the same fashion and again the pairs

TABLE III

RELATION OF CRITICAL FLICKER FREQUENCY TO LENGTH OF ALTERNATION INTERVAL

Surrounding field: Annulus, with a brightness of 1030 c p sq m

Subj.	First Int.	20 seconds				1 minute				2 minutes				4 minutes			
		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark	
		c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m
B	4′	28.82	.23	27.22	.22	29.36	.16	26.31	.19	29.54	.27	25.83	.18	30.22	.23	26.53	.23
B	20″	29.77	.26	29.17	.28	29.69	.21	28.46	.30	29.27	.26	27.49	.26	29.61	.24	27.04	.17
M	4′	22.31	.14	22.61	.12	22.94	.12	22.32	.10	23.35	.12	22.42	.12	23.84	.11	22.86	.14
M	20″	22.32	.11	22.67	.12	22.09	.19	21.79	.12	22.76	.14	21.58	.12	22.50	.15	21.63	.16
Ave...		25.81		25.42		26.02		24.72		26.23		24.33		26.54		24.52	
Diff...		.39				1.30				1.90				2.02			

of disc and annulus gradients become more separated at the longer intervals of alternation. In the disc gradients of this figure the no-surrounds point at 20-seconds is higher than its associated surrounds-illuminated point, and the two gradients cross. This is a phenomenon that scattered light and 'V-substance,' working together, might be expected to produce. The surrounds were 180 times as bright as the test object in this experimental situation. In terms of the hy-

TABLE IV

RELATION OF CRITICAL FLICKER FREQUENCY TO LENGTH OF ALTERNATION INTERVAL

Surrounding field: Disc, with a brightness of 1030 c p sq m

Subj.	First Int.	20 seconds				1 minute				2 minutes				4 minutes			
		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark		Surr. Ill.		Surr. Dark	
		c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m	c.f.f.	σ_m
B	4′	30.08	.30	31.15	.35	30.42	.23	29.28	.28	30.39	.29	29.07	.27	32.04	.45	29.68	.52
B	20″	31.32	.36	32.50	.33	29.29	.33	30.32	.35	29.25	.32	29.35	.26	29.19	.29	28.47	.36
M	4′	24.74	.16	24.40	.15	24.65	.18	23.18	.18	25.64	.16	23.76	.18	25.74	.20	23.25	.18
M	20″	25.04	.16	24.71	.19	24.63	.16	22.97	.15	24.20	.09	22.92	.14	24.00	.14	22.01	.09
Ave...		27.80		28.19		27.25		26.44		27.37		26.28		27.74		25.85	
Diff...		−.39				.81				1.09				1.89			

pothesis, the effect of 'V-substance' evidently carries over so easily into the short dark interval that the effect of scattered light in the surrounds-illuminated interval serves to achieve a relative depression of the c.f.f.

The prediction from the 'V-substance' hypothesis outlined earlier in this paper was that the gradients of c.f.f. with surrounds and without surrounds would tend to separate as one proceeded from short to long alternation intervals. That this occurs has already been in-

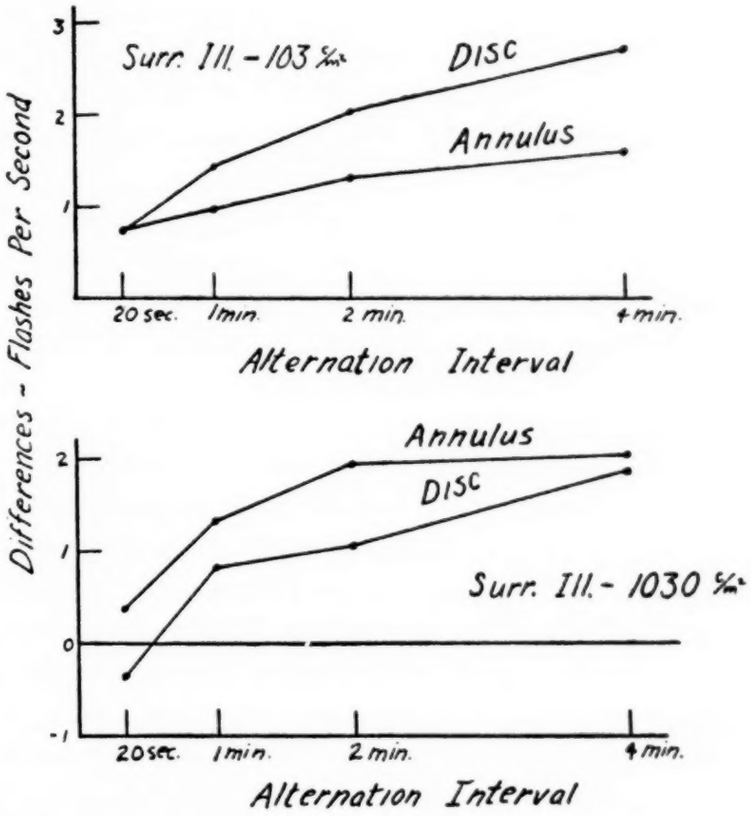

FIG. 5. Differences between the critical flicker frequencies with and without a surrounding field for various intervals of alternation and for both kinds of surrounding field.

dicated in Figs. 3 and 4. It will be more readily evident from Fig. 5 in which are plotted the differences in c.f.f. between the surrounds-illuminated and surrounds-dark conditions for each of the other stimulus variables. The positive slope of all these gradients is that called for by the hypothesis.

Some comparisons among the gradients are of interest. At the lower brightness of surrounds the differences are greater for the disc than for the annulus. This effect might have been the result of either, or both, 'V-substance' and neural interaction in the retina, in as much as there is not only a greater area with the disc but the added area is immediately adjacent to the test object. At the higher

brightness of the surrounds the levels of the disc and annulus gradients are reversed. This change is probably the result of the increasing effect of scattered light. The surrounds in this case are 180 times as bright as the test object and the immediately adjacent area would produce a large amount of non-imaged illumination in the test area during the dark phase of the flicker cycle.

Discussion

The theoretical background out of which this experiment developed, and the description of the type of experiment set up to test the 'V-substance' hypothesis, have already been detailed and need not be repeated here. The results of the experiment, confirming the hypothesis, have also been reviewed. It remains only to summarize some general implications.

First, the parallel effects on foveal c.f.f. produced by the disc and the annulus are certainly not to be explained in terms of neural interaction in the synaptic layers of the retina. We are evidently dealing with a process which occurs regardless of the placement of the interacting areas in the visual field.

The major findings of this study, presented in Fig. 5, permit an exclusion of any neural integrative processes as complete explanations of interaction phenomena. There is here a gradual change in reactive capacity which occurs and recovers in four minutes. Furthermore, the change is still incomplete at the end of four minutes. The only neural process that has anything like these characteristics is learning, or conditioning, and we are quite definitely not dealing with that sort of situation here.

The confirmation given the 'V-substance' hypothesis by this study is more qualitative than quantitative, largely because the hypothesis is stated in non-quantitative terms, and also because there are hardly sufficient relevant data yet to permit an exact formulation of the assumed chemico-physiological process. There is confirming eivdence, however, that 'V-substance' is a step in the right direction , in the rough parallel between the course of events here depicted and light and dark adaptation. The mechanism of 'V-substance,' having similar rate characteristics, is doubtless of the same general nature.

In the study here described the procedure was set up to get a body of data in sufficiently large groups to secure statistical solidity in spite of the inherent variability of flicker data (**19**). This became the more important since exploratory work had shown the expected changes would be small. The procedure of alternating the presence and absence of the surrounding field at different rates offered a way

to secure large bodies of strictly comparable data by which to make a check of the hypothesis. The disadvantage of the procedure lies in the fact that it tends to obscure the evidently rapid changes which take place in the early moments of exposure to the surrounding field by averaging early and late readings.

The next step, which is already under way, is to plot the changes in critical flicker frequency, in as fine time units as possible during continuous exposure to surrounding fields of varying character. The high variability of the flicker limen will require extensive measurement with less possibility of satisfactory averaging, but the results should yield data of significance in discovering the exact time relations of the 'V-substance' process.

Summary

Critical flicker frequency was measured by the method of limits in a 2° foveal area, of 5.8 c p sq m brightness, viewed monocularly through a 2 mm pupil. Two surrounding fields were used: a circular area of 42° diameter, with the test area at its center; and an annulus, of 12° radial width, concentric with the test area and separated from it by an 8° dark space. Both surrounding fields were used with brightnesses of 103 and 1030 c p sq m.

During each experimental session threshold measures were made continuously in four 16-minute periods, each preceded by dark adaptation. Half of the 48 liminal readings secured in each period were made with the surrounds illuminated; half, with the surrounds dark. In one period the surrounds illumination was on for four four minutes, then off, on, and off for the three following four-minute intervals. In the other three periods the alternation intervals were two minutes, one minute, and twenty seconds. Each procedure was repeated in another session with the order of the alternation intervals reversed.

The differences between the paired limens, obtained with and without surrounds in each 16-minute period, are the significant data of the experiment. For all surrounds and illumination conditions, they show a gradient of increasing difference between the limens with increasing length of the alternation interval.

It is concluded that no mechanism of neural interaction in the optic system can account for these data. Rather, they are considered critical evidence for the 'V-substance' hypothesis, previously proposed, according to which some primary or secondary product of the initial photosensory reaction may pass to, and increase the 'reactility' of, distant areas in the retina.

(Manuscript received May 3, 1941)

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A SCALE FOR THE JUDGMENT OF FACIAL EXPRESSIONS

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Much of the early work on Facial Expression was concerned with the accuracy of judgment. The results of these studies showed that observers were much less successful at recognizing facial expressions than one might expect. There are undoubtedly many factors leading to this inaccuracy, such as the absence of cues from voice, movement, and general situation. But another important element is the difficulty in finding the correct name for the expression. An experimenter starts with a number of common words, such as 'anger,' 'contempt,' and 'mirth.' He then tries to 'express' corresponding emotions or attitudes, and takes pictures of the attempts. He next shows the pictures to subjects, and counts their judgments as correct if they give him back his original names for each picture. When he examines his results he finds very few 'correct' judgments. The first obvious improvement is to consider synonyms as correct. But how similar must the synonym be to the original word? One can improve the situation by limiting the subject to 30 or 40 different words, thus eliminating some of the more subtle terms that cause difficulty. But this method still leaves much to be desired.

The next step in procedure is exemplified in the work of Jean Frois-Wittmann (**2**). He eliminated one major source of error by studying merely the consistency of judgments. Thus a picture was not said to represent 'rage' because he posed it to represent that emotion. Each picture was considered as a stimulus and Frois-Wittmann studied the inter-relationships between the names it evoked from different subjects. He still had the difficulty of handling synonyms and near synonyms, which he solved to some extent by grouping together all pictures which had as a modal judgment the same name. He then proceeded to find relationships between these groups by looking for secondary frequencies.

Hulin and Katz (**4**) took the final step by eliminating names entirely—at least in a formal sense. They asked their subjects to sort 72 of the Frois-Wittmann pictures into as many piles as they wished, putting similar pictures in the same pile. They then simply tallied the percentage of subjects which placed any given pair of pictures together.

By this time we have gotten pretty far from the problem of "How well do people recognize facial expressions?" Anyone who has attempted to summarize the work of Hulin and Katz to a class of students will recognize the difficulty. If one is going to work with complex stimuli like facial expressions he might as well use methods that will yield communicable results. Such a method was suggested by Woodworth (**8**). His ingenious idea of a 'scale' of facial expressions would clear up most of the difficulties with criteria of correctness among partial synonyms. If it were possible to arrange facial expressions along a continuum, instead of in an indefinite number of categories, it would be possible to obtain some numerical measure of divergence in judgments.

Woodworth's idea is not unlike the scales used in attitude measurements in that it is based on judgments. After some manipulation of the published results of Feleky (**1**), he obtained a scale with the following 6 steps: 1. Love, Happiness, Mirth; 2. Surprise; 3. Fear, Suffering; 4. Anger, Determination; 5. Disgust; 6. Contempt. Pictures which did not seem to fit the scale could be placed in a category called 'Scattering.' Using this scale on Feleky's data Woodworth found a correlation between pose and judgment of +.92. He reports that data from Ruckmick (**7**) and Gates (**3**) also fit neatly into the same scale. In view of these promising results it seemed worthwhile to investigate the characteristics of the scale in more detail than Woodworth reports. The present experiment was designed with that purpose in mind.

Method

The pictures used were the 72 chosen from the Frois-Wittmann series and published by Hulin and Katz (**4**). Hulin kindly furnished 3 sets of these pictures, printed on one side of a slightly smoother stock than that used in the published article.[1] Margins and numbers were trimmed off and the pictures unobtrusively numbered on the back. Three identical sets of 72 pictures each were shuffled and given to each of 45 subjects to sort into 7 bins. The bins were arranged in a row, and labelled (from left to right) with the names of the six categories in their assumed order. The seventh bin was used for the 'Scattering' expressions. Each subject was told to sort the pictures into the appropriate bins, using the 'Scattering' bin for any that didn't seem to belong elsewhere. The pictures were then removed from the bins by the experimenters, and tabulated. As they were tabulated they were dealt irregularly into several packs, and then shuffled before they were given to another subject. (The preliminary dealing into packs was necessary to insure a good redistribution, since the paper pictures tended to cling together during shuffling.) The 45 subjects were members of a course in Experimental Psychology, and were almost evenly distributed between the sexes. The 6 experimenters were also students in the course. Each subject took about a half hour to sort the 216 (3 sets of 72) cards.

Results and Discussion

The results are summarized in Table 1 and Figs. 1 and 2. The description of these data can best be taken up along with our discussion.

[1] A partial set of these pictures can be obtained from the C. S. Stoelting Co.

TABLE 1

THE DISTRIBUTION OF 72 PICTURES OF FACIAL EXPRESSION IN THE 6 CATEGORIES OF THE WOODWORTH SCALE

Identifying numbers (first column) are those of Hulin and Katz. For further description see text.

No.	1	2	3	4	5	6	Average	Average Deviation
	Love, Mirth, Happiness	Surprise	Suffering, Fear	Determination, Anger	Disgust	Contempt		
6	67	5	0	2	2	52	.55	.58
69	114	2	0	4	8	6	.76	.44
32	112	0	0	1	2	7	.89	.21
31	72	5	0	1	3	0	.95	.22
49	24	22	2	11	4	19	.98	1.05
68	118	1	0	1	0	4	1.00	.07
72	132	0	3	0	0	0	1.04	.08
3	95	9	0	0	1	3	1.04	.16
70	124	2	1	1	0	0	1.05	.10
4	103	4	1	0	0	0	1.06	.11
52	80	9	4	0	2	7	1.06	.32
71	120	10	0	0	0	1	1.07	.14
5	124	5	3	0	0	0	1.08	.15
11	45	42	0	0	0	31	1.09	.64
50	74	5	3	13	0	13	1.34	.79
10	39	62	8	0	1	3	1.65	.58
29	0	124	2	0	0	0	2.02	.035
27	2	117	7	0	0	1	2.02	.104
19	10	81	13	0	0	0	2.03	.25
28	0	108	8	0	0	0	2.07	.13
26	2	98	22	1	0	1	2.20	.35
53	0	68	52	0	0	0	2.43	.49
30	1	60	54	2	1	2	2.47	.57
48	35	15	49	12	3	3	2.50	1.01
44	0	54	64	0	0	1	2.57	.51
1	5	50	18	22	0	0	2.65	.81
9	7	11	86	0	2	5	2.67	.43
55	0	26	61	0	0	1	2.70	.45
62	3	46	33	36	3	1	2.90	.81
47	0	4	111	0	3	0	3.02	.10
54	0	0	119	2	3	0	3.06	.12
66	0	0	104	6	1	0	3.06	.12
45	5	10	96	4	8	3	3.07	.44
37	0	15	82	11	4	2	3.09	.41
46	0	19	75	16	4	2	3.09	.48
35	7	21	59	37	3	2	3.10	.69
43	15	18	29	21	1	12	3.10	1.14
25	10	12	11	29	5	7	3.37	1.20
42	9	2	81	6	22	6	3.38	.82
57	0	23	51	20	18	7	3.46	.95
33	1	0	70	10	20	0	3.47	.71
34	0	0	43	66	19	0	3.81	.55
20	1	4	52	9	5	22	3.87	1.17
56	4	3	49	8	34	17	4.00	1.17
36	0	0	2	120	10	0	4.06	.14

TABLE 1 (*continued*)

No.	1 Love, Mirth, Happiness	2 Surprise	3 Suffering, Fear	4 Determination, Anger	5 Disgust	6 Contempt	Average	Average Deviation
60	0	0	4	110	7	5	4.10	.25
39	0	0	2	112	6	5	4.11	.23
65	0	12	6	68	22	12	4.13	.69
7	0	9	9	54	13	16	4.18	.79
61	8	1	30	30	12	7	4.20	1.00
63	2	10	5	72	29	15	4.21	.74
2	0	5	34	12	23	22	4.21	1.22
18	0	1	0	109	13	8	4.22	.39
17	0	0	2	92	16	10	4.28	.48
38	0	1	13	71	20	16	4.31	.68
16	2	0	5	88	7	10	4.34	.53
23	2	6	17	8	29	14	4.38	1.11
64	0	1	1	88	16	22	4.45	.68
59	0	0	3	62	40	15	4.56	.66
41	0	1	18	29	41	24	4.60	.87
40	3	1	9	17	91	12	4.86	.50
24	1	0	8	17	33	62	5.25	.85
58	0	0	0	23	55	59	5.27	.64
8	0	0	13	1	31	80	5.42	.74
51	9	4	3	16	28	50	5.53	.85
13	5	1	2	10	12	90	5.74	.53
12	4	0	1	5	21	94	5.76	.44
22	2	2	1	0	12	93	5.97	.21
21	12	3	0	3	6	99	6.05	.28
14	36	4	0	6	14	54	6.18	.63
15	50	0	0	3	12	54	6.27	.61
67	42	5	0	1	3	59	6.42	.58

A. The Mathematical Treatment of the Judgments

The detailed results are presented in Table 1. Below each of the 6 steps of Woodworth's scale is entered the actual numbers of times each picture [2] was placed in this category. (The seventh, or 'Scattering' category has been omitted, since it was not used in the computation.) The last two columns headed 'Average' and 'Average Deviation' will be explained later.

The Nature of the Scale.—The pictures have been listed in an order which places those must consistently judged to belong in step 1 at the top, and those in step 6 at the bottom, with intermediate ones in proper order. This causes the modes to run diagonally across the page. There should be some spread to neighboring categories,

[2] The identifying numbers used throughout this paper are those of Hulin & Katz. Frois-Wittmann did not identify his individual pictures in any available data.

but it should be in a regular fashion. Inspection shows this to be true for pictures in categories 2, 3, 4, and 5. Of course there are some pictures which spread well across all categories. We will examine these pictures later. But if we are dealing with a linear series there should be very few, if any, entries in the upper right and lower left corners of the table. Such entries would mean that there was similarity between the ends of the scale. But that there are such entries is obvious. For example, the first picture listed (6) has 67 entries in its modal category, step 1. We should expect it to show its next highest value in step 2, then step 3, etc., with none in step 6, which is at the opposite end of the scale. Instead it has a very high number (52) of entries in step 6. This can be understood most readily if we consider the scale to constitute a circle, or recurrent series, like the hues of the spectrum, or the tones of a pitch scale. Then the pictures of step 1 would be as apt to spread into step 6 as to step 2. Detailed examination of the judgments of pictures which have their modes in scale position 1 shows as much spread between 1 and 6 as between 1 and 2. Similar spread is found from step 6 to steps 1 and 5.[3] It is thus clear that we are dealing with a circular scale, and not a straight line.

The next question that may be asked is whether we have a true scale, or simply 6 categories. In other words, are pictures distributed evenly over the scale, or do they fall in 6 groups? It is obvious that our method would force single judgments into 6 categories, but if the pictures are distributed along a continuum, we should find pictures split in various proportions between two adjacent categories. Thus picture No. 47 has a high mode in step 3, and No. 36 has its mode in step 4. Picture No. 34 has its mode in step 4, but also a high incidence in step 3. It is thus somewhere beteeen pictures No. 47 and No. 36.

To place the pictures more precisely, it is only necessary to find the average scale position of each picture. But this cannot be done by simply numbering the steps 1 through 6, multiplying by the number of items in each step, and dividing by the total number. The circularity of the scale prevents this. For example, our first illustration above (No. 6) is obviously about halfway between step 1 and step 6. This does not mean at position $3\frac{1}{2}$, as simple averaging would yield, but at the opposite side of the circle (which may be designated as $6\frac{1}{2}$ or $\frac{1}{2}$, corresponding to the 30° point on a circle, or 1 o'clock on a clock dial). It is clear, then, that to get meaningful averages we must first find the mode, and then work both ways around the circle.

[3] The first 15 pictures of Table 1 show modes in step 1. They were placed 121 times in step 2, and 143 times in step 6. Similarly the 9 pictures (at the bottom of the table) with modes in step 6 fell 227 times into step 5, and 161 times into step 1.

As an example, take the first picture in the table (No. 6). Step 1, the mode, was temporarily given a value of 0. Steps 2 and 3 were given values of +1 and +2 respectively. Similarly, working backward, steps 6 and 5 were given values of −1 and −2. The odd step was treated as −3. (It was sometimes treated as +3, or the entries divided between +3 and −3, depending on the form of the distribution.) Multiplying by the frequencies and adding, we have $(67 \times 0) + (5 \times 1) + (0 \times 2) + (52 \times -1) + (2 \times -2) + (2 \times -3) = -57$. Dividing by N(128) we get −.45. This means that our mean is −.45 scale steps from the mode (step 1.00) or at an absolute scale position of .55. Similar treatment of the values for each picture yielded the average values listed in Table 1. These mean values were used in arranging the pictures in order in the table. Average deviations were calculated from these computed means by a similar procedure, and are also presented in Table 1. The method of computing average deviations is not completely legitimate for it inflates the average deviations for those pictures midway between two categories by as much as .50. A picture which everyone placed in step 1 would have a scale position of 1.00 and an average deviation of 0.00. But a picture which belonged halfway between category 1 and 2 would at best be divided equally between these two positions, yielding a correct scale position of 1.50, but an inflated average deviation of .50, instead of 0.00.[4]

The results are presented in graphic form in Fig. 1. The length of the line indicates the average deviation of each picture, and the center marks the picture's scale position (whole numbers, as 1.00, 2.00, etc. are considered at the middle of the step). Examination of this figure tells us a lot about the behavior of this series of pictures on this scale. In the first place, the means progress at a fairly constant rate diagonally across the page, suggesting clearly a scale, rather than 6 discrete categories. There are certain clusters that suggest categories, particularly in the 'Love, Happiness, Mirth' step. Whether this is due to the nature of the scale or to the choice of pictures is hard to say. That it is due to the composite nature of the step is suggested by the fact that the other composite steps ('Fear, Suffering,' and 'Anger, Determination') also show some tendency for clusters. It may also be noted that the average deviations (see bottom of Fig. 1) are small in step 1, so there may well be a point on the scale in this step around which pictures would tend to cluster in any series.

[4] After this had been written, our attention was called to Ross' paper 'A statistic for circular scales' (6). He favors a vectorial method, but only if one has a continuous series of equal steps and true opposites at opposite ends of any diameter:—in other words, a true circle. Our scale fulfills the first condition, continuity, but possibly not the other two. It may well be oval in form. Therefore, our method of treatment seems preferable.

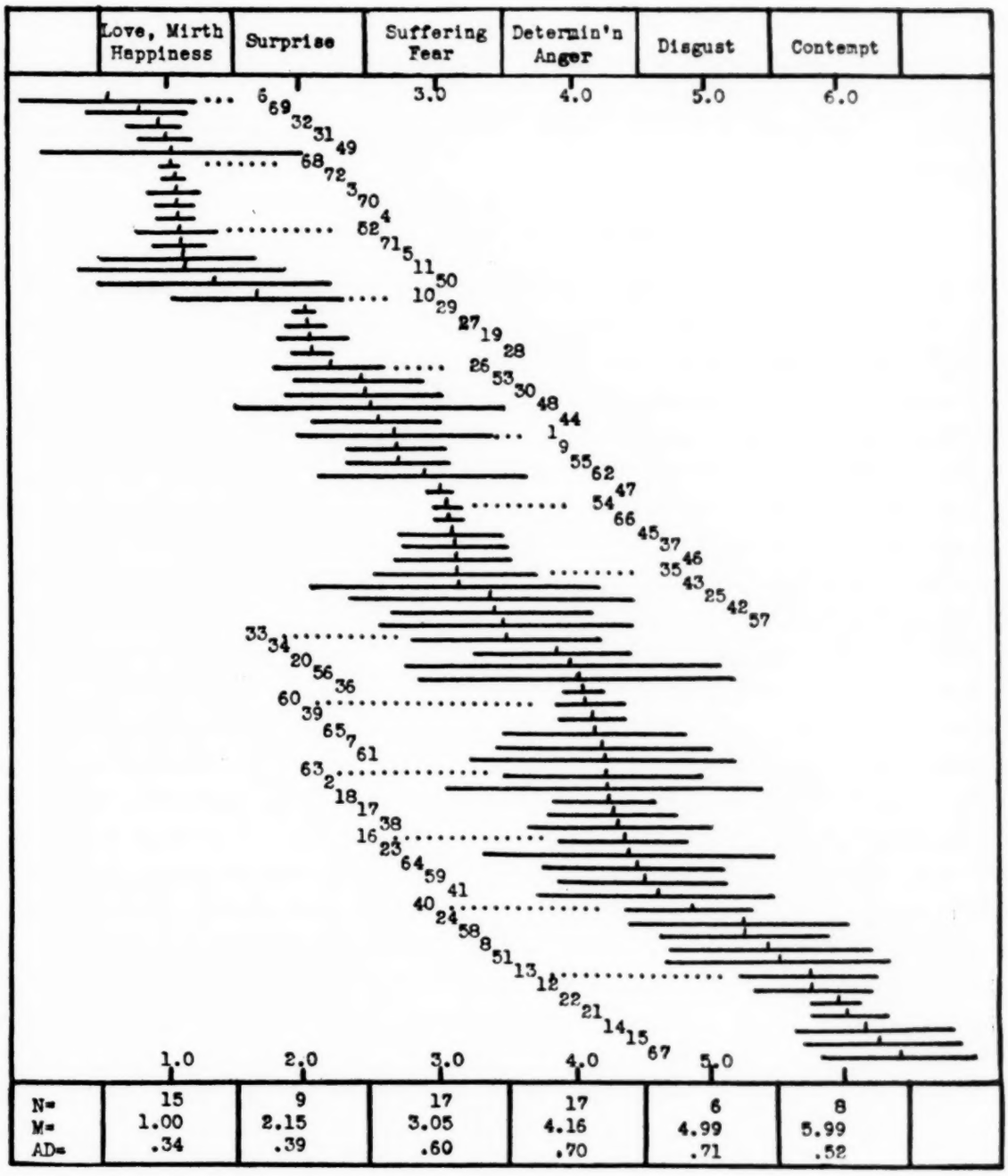

FIG. 1. Means and average deviations of the distribution of the pictures. One A.D. has been plotted either side of the central point. Data are summarized by categories at the bottom of the figure. See text and Table 1.

The next question suggested by Fig. 1 is whether or not the steps are roughly equal in size. It is not clear just how this should be answered. The number of pictures falling in each step has been totalled at the bottom of the figure (together with mean scale value, and average deviation). It will be seen that step 5 has only 6 pictures in it, while step 3 has 17 pictures. Is this a function of the scale or of the pictures? Average deviations vary from .34 to .71,

which might suggest unequal steps.[5] But whatever the cause of these variations in the characteristics of the steps, it should be noted that the variations themselves are not too great to preclude the use of the scheme as a rough scale for describing large series of facial expressions.

B. The Meaning of the Scale

Up to this point we have said nothing about the factors on which the scale is based. Six categories have been shown to constitute a rough scale along which (or more properly, 'around which,' since the scale is recurrent) pictures of facial expression may be distributed. Perhaps we should stop here, and say that we have adequately described the scale. But it would seem that there must be some underlying variables that enable us to construct such a scale. The analogy of the spectrum immediately occurs. The spectrum is, in a sense, nothing but a scale along which one can distribute colors. But underlying it is an orderly change of wave length, and presumably some parallel change in receptor process. Is there any comparable basis for our present scale? To facilitate this discussion, Fig. 2 has been prepared. On it 54 of the 72 pictures have been placed in their appropriate scale positions. (To avoid too great a reduction in the size of the pictures certain expressions have been omitted; particularly alternate pictures in categories 1, 3, and 4.) Through the base of each picture is a line whose length indicates the average deviation of its scale position. (The more reasonable procedure, that of plotting one A.D. either side of the central scale position, as in Fig. 1, was impractical in Fig. 2.) In Fig. 2 vertical position is meaningless, and is used only as a device to spread the pictures out and make the categories more clear. Figure 1 gives a much better idea of the scale position of the pictures. But Fig. 2 makes it possible to get some idea of the actual pictures as they fall along the scale.

A careful study of the pictures in Fig. 2 suggests that the most important variable in the scale is the Pleasantness-Unpleasantness element. The first category is rather obviously one for pleasant emotions, as indicated by its name (Love, Mirth, Happiness). The most unpleasant emotions would fall in categories 3 (Fear, Suffering) and 4 (Anger, Determination). These categories should, therefore, be opposite category 1 on the circular scale. Actually category 4 would be opposite category 1 if the scale were composed of equal steps. But as we have indicated above, the number of pictures

[5] One is tempted to explain the smaller average deviations at the ends of the scale by assuming a curtailing of the ends of the distribution in the terminal categories. But a circular scale has no terminal categories—we have merely cut the scale between 0 and 6 for convenience in manipulation.

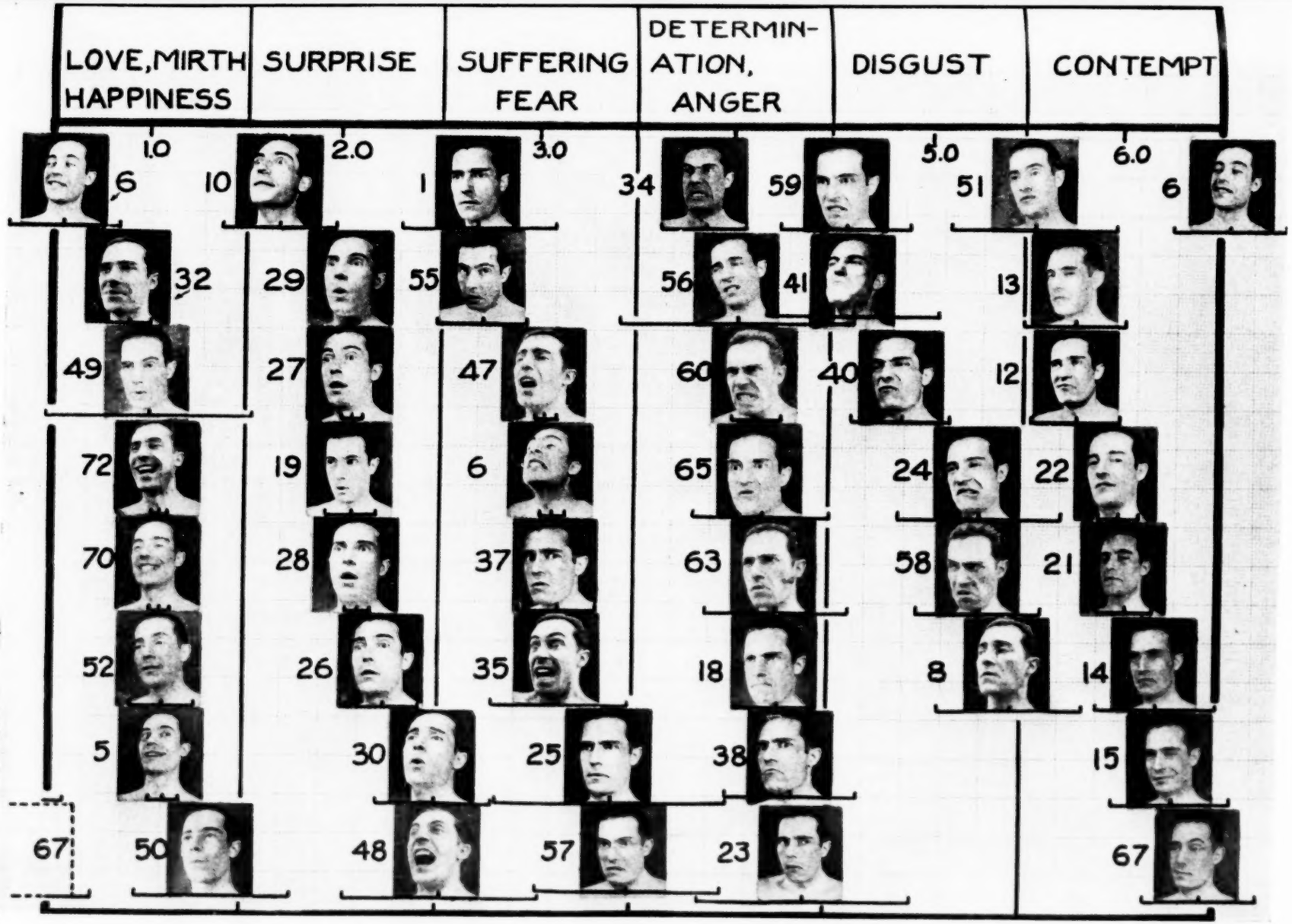

FIG. 2. Scale positions of 46 of the 72 pictures. Horizontal bars represent 1 average deviation. Picture No. 6 has been duplicated at upper right corner to suggest the circularity of the scale.

falling in the right half of the scale is slightly smaller than that in the left half. This would suggest that steps 5 and 6 are too small and would account for the apparent slight displacement of the unpleasant expressions. The intermediate categories seem truly intermediate in affective tone. Surprise clearly varies between pleasant and unpleasant, depending upon the nature of its object. Disgust is close to the most unpleasant emotions. One does not have to be a Psychoanalyst to see a distinct element of pleasantness in contempt. So we may plausibly consider our major variable to be affective tone. It should be noticed that the mouth seems to 'carry' much of this factor, and that there are some rather interesting double curvatures of the lines of the lips in the transitional zones (2, 5, and 6).

But if our scale is circular in form, there must obviously be some other variable involved. Otherwise our circle would flatten out, yielding simply a linear continuum of Pleasantness-Unpleasantness. In other words there must be something that keeps category 2 (Surprise) from fusing with categories 5 (Disgust) and 6 (Contempt). An examination of the pictures in these categories furnishes us with a tentative suggestion. Category 2 is characterized by a sort of wide-eyed expectancy, an openness to stimulation. On the other hand, category 5, and to some extent, category 6, suggest an aloofness, an effort to shut out stimulation. The contrast is particularly clear in the eyes. The second axis of our circular scale may then be something like 'Attention-Rejection.'

Up to this point we have considered our pictures to be disposed around the circumference of the circle. But many of them might well be placed inside the circle. For example, a truly relaxed face might belong at the center, where the two axes intersect. A faint smile would fall on the Pleasant-Unpleasant axis, somewhere between the indifference point and the Pleasant end. The most appropriate figure to represent our results thus becomes a surface, roughly circular in form. By forcing the subjects to sort by categories we have largely eliminated the intensive variable from our results, so that our scale positions are referred to the circumference of the surface.

It would be interesting to know the exact shape of the surface. The tendency for the pictures to collect in categories 1, 3, and 4 suggests that the Pleasant-Unpleasant axis is the major one, and the Attention-Rejection dimension is less important. This would make the surface an oval, rather than a circle. An attempt to demonstrate this by simple arithmetical manipulation was made. The 72 pictures were treated as a circular continuum, and divided into 4 equal parts, or quadrants, each containing 18 pictures. Scale position 1.0 was arbitrarily chosen as the central point of one quadrant, called 'Pleasant.' Following around the scale the other 3 quadrants were called

'Attention,' 'Unpleasant,' and 'Rejection.' If the P-U axis is actually longer than the A-R axis, there should be less spread of P pictures into U categories (and vice versa) than there is of 'Attention' pictures into the 'Rejection' categories (and vice versa). This seems to be true, but the difference is slight. Those pictures whose scale positions were in the P or U categories have fallen in the opposite quadrants 2.4 percent of the time. Similar 180° 'errors' of pictures in the Attention and Rejection categories occur in 3.1 percent of the judgments. This difference is too slight to be of great significance. It is possible that some other technique, such as a form of factor analysis, may eventually be of value in determining the axes, and the factors basic to the scale. Before further mathematical treatment is made, however, we should probably improve the original data. The use of a linear arrangement of sorting bins should certainly be avoided, for it implies a linear continuum and might well influence the subjects' judgments. Now that we know the scale to be circular, we should use a set of 6 sorting bins arranged around the circumference of a turntable, with the central portion of the disc reserved for 'Scattering' expressions, and for neutral pictures. Another possible approach might be made by having the subjects attempt to place each picture on a graphic representation of the surface. The scale positions could then be described in terms of polar coördinates.

The present section may be summarized by saying that the surface is probably roughly oval in form, with Pleasantness-Unpleasantness the major axis, and Attention-Rejection the minor axis. To give a complete description of all facial expressions would call for the addition of quite a few factors or dimensions of decreasing importance. The omission of such additional factors and of an intensive dimension undoubtedly led to the wide distribution of some pictures. It also made necessary the use of an additional bin labelled 'Scattering' for unclassified pictures. Some pictures (No. 23, No. 25) were placed in this bin half the time. But a scale involving only the two dimensions we have described above fits a large series of pictures surprisingly well.

C. A Comparison with Other Investigations

One naturally wonders if the circularity is an essential characteristic of the scale, or if it is due to some peculiarity of the pictures themselves, or of the method used in collecting the data. The consistency of the results favors the first interpretation. To clinch the matter it would be desirable to find the same characteristics in judgments obtained in the conventional ways from other series of pictures. But when one actually looks up material from other series he finds them very inadequate. The only evidence we could find from the

Ruckmick series (7) is very small. He has one picture (his No. 30) that was posed as 'contemptuous smile.' There are too few judgments on this picture to find how they are distributed, but the mere fact that the picture is named as it is suggests a position intermediate between categories 6 and 1.

The Feleky series (1) has 4 that might yield relevant data. Her picture No. 69 (Laughter) shows a high concentration in Love, Mirth, Happiness, and no spread to other categories. Picture No. 52, the only other with its mode in this category, is judged in a rather erratic fashion. Pictures No. 61 (Sneering) and No. 62 (Contempt) show little spread outside of synonyms within category 6. Thus Feleky's results do not show whether or not the circular trend appears in her series.

But Kanner's results (5), obtained 7 years later with some of the same pictures, are more in keeping with ours. He didn't use Feleky's pictures No. 69 and No. 52, so he had none in our category 1. But No. 61 (Sneering) had its mode in Contempt (category 6) and showed a spread of 10 percent to Disgust (category 5) and of 9.5 percent to Self-consciousness-coyness-pleasure-approval (probably all in our category 1). Picture No. 62 (Contempt) had its mode in category 6, and spread 16 percent into Resentment-dislike-disgust (category 5) and 9 percent into Pleasure-approval (category 1). The spread from category 6 more or less equally to categories 1 and 5 is exactly what we have found with the Frois-Wittmann pictures. One wonders why Kanner's results agreed with ours, while Feleky's didn't. Is it because Feleky's were obtained in a less cynical age? It is more likely that it is the choice of judges. Feleky had '100 reliable subjects' who may well have been influenced by personal acquaintance with her. Kanner used medical students who had never known the original of the photographs. They are probably more like our own students than were Feleky's subjects.

Comparisons of judgments obtained by the free-naming technique are very hard to place on our scale, since there are many nuances that do not fit into our categories. This might be used as an argument against the scale. But that there is something underlying the positions at which our subjects placed the pictures is clearly shown by a comparison with Frois-Wittmann's original results. In his Table 1 (2, p. 122) he has summarized 11,965 judgments on 227 pictures in terms of 'average percentages of all judgments for each judged expression occurring as a mode.' The order of terms used in constructing his table represents "an approximate representation of the closeness that exists between various points of high frequency" (P. 121). His order of terms, as listed in the left hand column of his table, matches ours very well, but only if we consider both as

circular scales. Ours reads clockwise, and is arbitrarily cut between steps 6 and 1. Frois-Wittmann's reads counter-clockwise, and is cut roughly between 1 and 2. Reading down his sequence of terms, we find the first 3 names in our step 1. Then follow 6 terms in step 6, 2 in step 5, 4 in step 4, 2 in step 3, and perhaps 5 in step 2. The next 8 of Frois-Wittmann's terms do not fit our scale well. In terms of our scale Frois-Wittmann has inserted a new step, 'Crying, Pain, Suffering' between steps 1 and 2. We would place most of the terms in this group between steps 2 (Surprise) and 3 (Fear, Suffering). Our placement would seem to fit the spread of Frois-Wittmann's judgment at least as well as his own order does, without sacrificing certain internal consistencies that our scale possesses. Finally, Frois-Wittmann's last two terms clearly fall in our step 1, completing the circle.

The fact that Frois-Wittmann's order of terms fits our version of Woodworth's scale so well lends strong support to the scale. Frois-Wittmann's judgments were collected without any of the possible 'suggestion' effects that a line of bins might produce. Further, it must be remembered that Woodworth originally based the present scale on Feleky's data, obtained on a different set of pictures. There is no indication in Woodworth's discussion (**8**) that he knew of Frois-Wittmann's work. To the writer, the fact that all of these diverse lines come together so nicely in the present scale is the first encouraging thing he has ever seen in results of studies of 'facial expression.' As a final check, it would seem desirable to repeat our present experiment, using another series of pictures, such as Ruckmick's (**7**). This will probably be done in the near future.

Summary and Conclusions

I. In a study of Woodworth's scale of Facial Expression each of 45 students sorted 216 pictures into a rack. The rack had 6 main bins, arranged in the following order:—I. Love, Happiness, Mirth; II. Surprise; III. Fear, Suffering; IV. Anger, Determination; V. Disgust; VI. Contempt; and an additional bin, 'Scattering,' that served as a discard pile. The pictures used were 3 sets of the 72 Frois-Wittmann pictures, shuffled into one deck.

II. Analysis of the distribution of pictures shows that the scale is continuous, rather than a collection of single categories. The steps are apparently reasonably equal, although steps 2, 5, and 6 may be smaller than the other three steps.

III. Contrary to the original assumption, the scale is clearly a recurrent or circular series, as indicated by the spread of judgments across the supposed gap between step 6 and step 1.

IV. The scale is probably not a true circle, but an elliptical surface, with Pleasant-Unpleasant as the long axis, and Attention-Rejection as the short one.

V. Comparison with results from other investigations using different methods and pictures substantiated the essential characteristics of the scale. It may thus serve to make orderly a chaotic field.

VI. Additional investigation is needed to refine the scale.

(Manuscript received May 27, 1941)

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STUDIES IN THERMAL SENSITIVITY: 17. THE TOPOGRAPHICAL AND FUNCTIONAL RELATIONS OF WARM AND COLD

BY WILLIAM LEROY JENKINS

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Previous investigations concerning the relation between warm sensitivity and cold sensitivity have been confined to mapping the warm and cold spots on the same area of skin to show their topographical relation. Probably the best study of this kind was that of Dallenbach [1] in which the spots were mapped on four different occasions. Usually warm spots and cold spots were found on different mm squares, but sometimes the same mm square would show both a warm spot and a cold spot.

The method of seriatim mapping provides a way of studying the topographical and also the functional relations of warm and cold. To show the topographical relations, we can map alternately with warm and cold stimulators, securing two sets of seriatim scores of known reliability which can be compared. To show the functional relations (that is, the effect of warm upon cold and vice versa), we can stimulate adjacent squares *simultaneously* with warm and cold, securing two sets of seriatim scores which can be compared with those obtained from single stimulation.

Procedure

The general method of seriatim mapping was similar to that used in the preceding studies of this series. The main alteration was the necessity of maintaining *two* sets of criteria for judgment: one for warm, the other for cold. The same reporting code was used for both: 0 for neutral, 1 for weak, 2 for medium and 3 for strong.

In the topographical study, a checkerboard of 3 mm squares was mapped on alternate rounds with 17° and 44°. Twelve mappings (6 warm, 6 cold) were made in the afternoon, and another twelve in the evening on the same map, but each session was treated as a separate unit in the later analysis.

In the functional study, a double stimulator was used. This consisted of two water-circulated cylinders, with their bodies widely offset in an insulating block, but their tips separated by only a few tenths of a mm. Thus it was possible to stimulate simultaneously one square with 17° and the adjacent square with 44°. For single stimulation of the same squares, either cylinder could be pushed up out of the way, while the other served as the active stimulator. With simultaneous dual stimulation, the subject reported first the intensity of warmth, then of cold. This was done because warmth rises more slowly and might be neglected if cold were reported as soon as it was experienced. Single stimulation and dual stimulation were used on alternate rounds. For the seriatim scores, the results of afternoon and evening sessions were combined.

[1] Dallenbach, K. M., The temperature spots and end-organs, *Amer. J. Psychol.*, 1927, **39**, 402–427.

Results

Topographical.—From the 88 pairs of maps secured in the topographical study, 43 pairs were selected which met all the require-

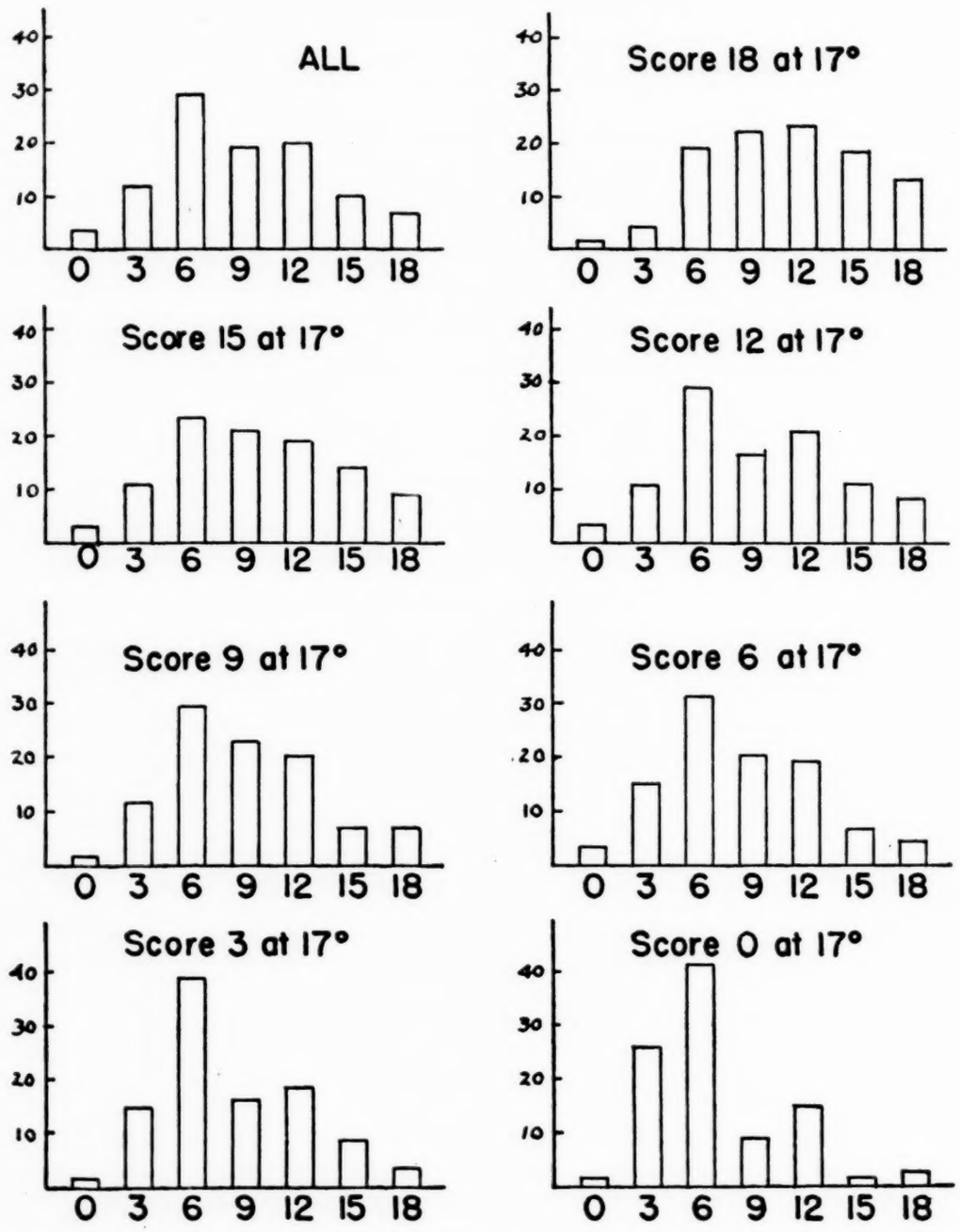

Fig. 1.

ments for consistency as described in the previous article.[2] These maps furnished 2005 squares which were scorable for both cold and

[2] Jenkins, W. L., Studies in thermal sensitivity: 16. Further evidence on the effects of stimulus temperature, *J. exp. Psychol.*, 1941, **29**, 413–419.

warm. The distribution of 44° scores among these 2005 squares was determined for each of the 7 levels of 17° scores. These frequency distributions are shown in Fig. 1, in which the ordinates are percentage of the total cases at each 17° score-level. The distributions at all 17° score-levels appear very much alike. It is evident that any cold seriatim score may be associated with any warm seriatim score, and that there is no *exact* relationship between warm and cold.

TABLE 1

CUMULATIVE DISTRIBUTIONS

44° Scores

		0	*3*	*6*	*9*	*12*	*15*	*18*
	18	1%	5%	24%	46%	69%	87%	100%
	15	3	14	36	58	77	91	100
17°	*12*	3	14	43	60	81	92	100
Scores	*9*	2	14	43	66	86	93	100
	6	3	18	50	70	89	96	100
	3	2	17	55	71	89	97	100
	0	2	29	71	80	95	97	100

TABLE 2

WARM-COLD CORRELATIONS FOR INDIVIDUAL MAPS

−.10	.01	.11	.21	.31	.41	.51	.61	
∞	.10	.20	.30	.40	.50	.60	.70	Total
13	5	8	5	6	2	1	3	43

There is, however, a tendency toward a mild positive correlation. This tendency is revealed more clearly by the data in Table 1, which shows the percentages cumulatively. For example, only 24 percent of the 17° scores of '18' are associated with 44° scores of '6,' but 71 percent of the 17° scores of '0' are thus associated. The general drift in this direction follows throughout the table. This positive tendency is likewise indicated by the correlations between warm and cold seriatim scores for the individual maps, shown in Table 2. Although the mode is plainly around .00, there is a definite bias toward low positive correlations.

TABLE 3

RELIABILITY COEFFICIENTS WITH SINGLE AND DUAL STIMULATION

	17°		44°	
	.80 up	.60 up	.80 up	.60 up
With Single.....	15	23	12	22
With Dual.....	11	21	8	20

TABLE 4

EFFECT OF SIMULTANEOUS WARM-COLD STIMULATION

	On Cold Seriatim Scores	On Warm Seriatim Scores
Increased	4	0
Unchanged	6	6
Reduced	5	9

What these correlations mean in terms of the appearance of the maps is illustrated by Fig. 2, which shows three skin areas with warm-cold correlations of .00, .67 and .23 respectively.

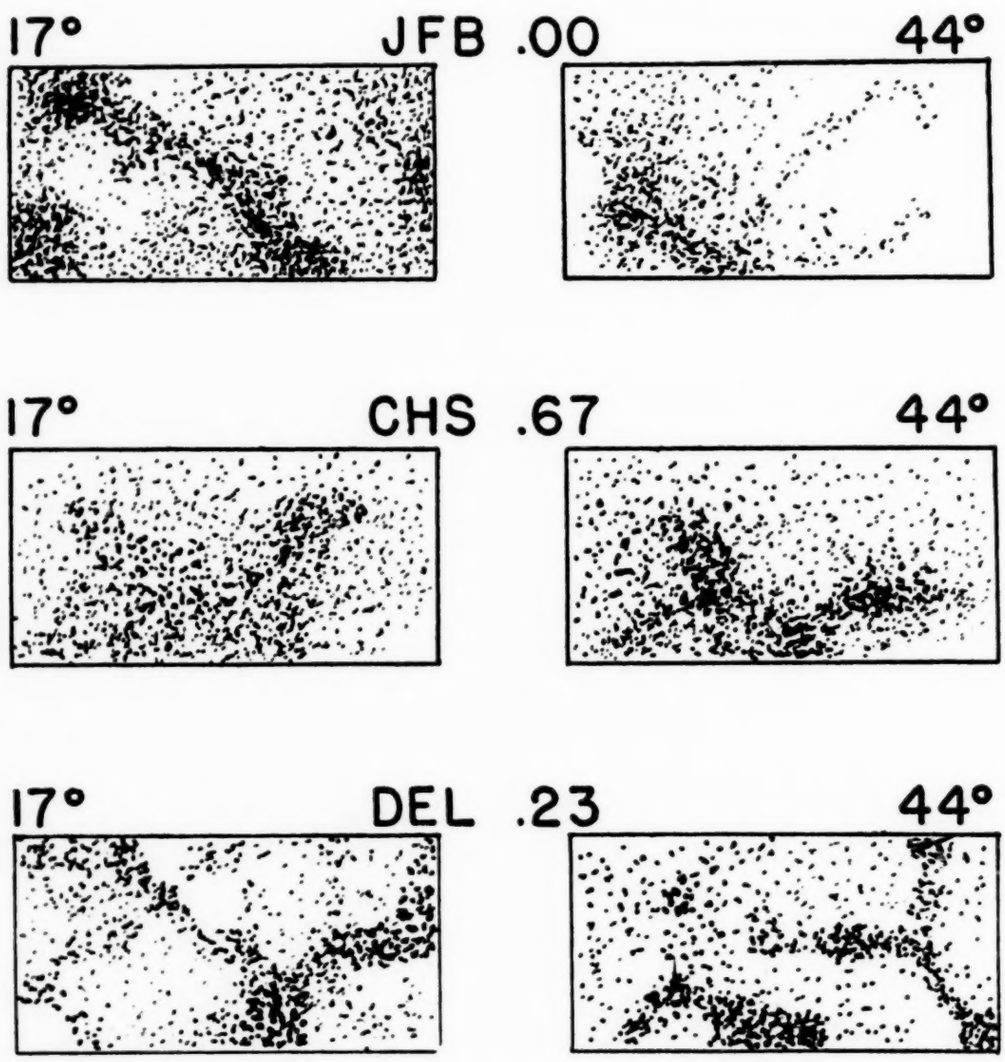

FIG. 2.

Functional.—In the functional study, the most surprising finding was the consistency with which subjects could report the intensity of both warm and cold, when stimulated simultaneously on adjacent squares. Some subjects found the task too confusing, but in many cases, the consistency was comparable to that exhibited with single

stimulation. Table 3 gives the results for all 33 subjects. With single stimulation at 17°, 15 correlations were .80 or better and 23 were .60 or better. With simultaneous dual stimulation, the corresponding figures were 11 and 21. Similarly good results were found for 44°.

To determine the interaction between warm and cold with simultaneous dual stimulation, the 15 most consistent subjects were selected and their single and dual scores compared. Table 4 shows the results. In the case of cold, there is no consistent effect on score level from the simultaneous presence of warmth. In the case of warm, however, there is a marked preponderance of *depression*. Even more significant is the absence of a single instance in which the warm score level was raised by the simultaneous presence of cold. This runs exactly contrary to what should be expected in terms of the Alrutz theory of heat, and confirms the earlier conclusion [3] that the Alrutz theory cannot be true.

Discussion

These experimental findings, both topographical and functional, add another link to the strong chain of evidence opposed to Nafe's vascular theory of thermal sensitivity.[4] Nafe maintains that there are no warm and cold receptors as such, but that warm and cold are experiences from patterns of dilating and constricting blood vessels. If this were true, we should expect to find a *high* positive correlation between warm and cold seriatim scores. But there is, at best, only a very low correlation and in many cases no correlation at all. Warm and cold act like two independent systems. To support Nafe's theory it is necessary to assume that some blood vessels give kinesthetic experience only when dilating; others only when constricting. Or else we must assume that some blood vessels are capable only of dilating; others capable only of constricting. Neither seems a very plausible hypothesis. If blood vessels must be made to mimic specific warm and cold receptors, the direct assumption that there *are* specific warm and cold receptors would be more parsimonious.

The functional results give a flat contradiction to Nafe's theory of heat. Nafe explains the experience of heat as caused by the simultaneous presence of dilation and constriction in the same area. When a subject is stimulated simultaneously with warm and cold on adjacent squares, we should expect to find many reports of *heat* in

[3] Jenkins, W. L., Studies in thermal sensitivity: 8. Analytic evidence against the Alrutz theory, *J. exp. Psychol.*, 1938, 23, 417–422.

[4] Jenkins, W. L., A critical examination of Nafe's theory of thermal sensitivity, *Amer. J. Psychol.*, 1938, 51, 424–429. Nafe's vascular theory and the preponderance of evidence, *Amer. J. Psychol.*, 1939, 52, 462–465.

place of separate reports for warm and cold. But the subjects are able to report warm and cold as *separate* experiences quite consistently, and the intensity of warmth tends to be *reduced* by the simultaneous presence of cold, never increased.

The appearance of the maps in Fig. 2 suggests a possible explanation for the bias toward a low positive correlation between warm and cold seriatim scores. The regions of high sensitivity on these maps appear to follow definite streaks. This suggests that these streaks may mark the pathway of bundles of nerve fibers whose ramifications supply most richly the immediate vicinity of the bundle. Neurons from warm receptors and neurons from cold receptors might be combined in the same anatomical bundle, although the two remain functionally independent systems. The commonality of the supply routes would then encourage a low positive correlation in their seriatim scores. This hypothesis provides an interesting subject for further research.

Summary

Alternate seriatim mapping indicates that warm and cold are distributed topographically as two independent systems. The lack of correlation is evidence against Nafe's vascular theory of thermal sensitivity; since we should expect a high correlation if warm and cold were due respectively to dilation and constriction of the same blood vessels.

Seriatim mapping *simultaneously* with warm and cold on adjacent squares provides evidence of the functional relations. Again, warm and cold act as two independent systems. Subjects report the two experiences from simultaneous dual stimulation with nearly as high consistency as with single stimulation. The score level for cold is generally unchanged by the simultaneous presence of warmth. The score level for warm is frequently reduced, but never increased, by the simultaneous presence of cold. This provides evidence against the Alrutz theory of heat, and also against Nafe's vascular theory of heat as based on the presence of constriction and dilation simultaneously.

The presence of a slight correlation between warm and cold in some areas may be due to the commonality of the supply routes. This is an interesting hypothesis for further research.

(Manuscript received April 29, 1941)

THE EFFECT OF AMPHETAMINE (BENZEDRINE) SULFATE ON THE STATE OF MOTOR CENTERS *

BY ERNST SIMONSON AND NORBERT ENZER

In a previous series of experiments (**13**) the relief of fatigue of the central nervous system by Amphetamine was accompanied by a consistent increase of the fusion frequency of flicker. On the days when Amphetamine was not administered the fusion frequency decreased at the end of the working day (**12**). In the occupations of the subjects investigated, muscular effort was negligible, so that the general fatigue was due to fatigue of the central nervous system. There is evidence (**11**) that in such occupations fatigue is located primarily in the sensory centers, and these experiments may be looked upon as further confirmation of this view.

Performance and fatigue in different types of work are due to different physiological functions. Without special investigations on the effect of Amphetamine in different types of work it is impossible to arrive at generalizing conclusions. It seems probable that the action of Amphetamine affects various functions and various types of fatigue differently. There is some evidence for this in Ivy's and Krasno's review (**5**) on Amphetamine sulfate, but the analysis of the Amphetamine effect is far from being complete.

Therefore, in addition to previously reported experiments, the action of Amphetamine sulfate on the state of motor centers was investigated at Dr. Ivy's suggestion.

The maximum number of impulses a center is able to emit (efferent function) or to perceive (afferent function) is an important and sensitive index of its functional state (Sherrington **10**, Wedenski **16**). The simplest method for determining the maximum frequency of motor impulses seems to be the measurement of the maximum frequency of finger movements. The findings of different authors (**2, 3, 4, 6, 7, 9**) indicate a close relationship between chronaxie, the maximum frequency of discharge of the motor centers and the speed or frequency of movements. As the weight of the fingers and consequently the inertia in finger movements is small, the relationship between the maximum frequency of finger movements and of the actual number of motor impulses is close. Lehman (**8**) has shown that the number of motor impulses is directly proportional to the speed of finger movements. The actual frequency of motor impulses in vol-

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untary movements is higher than this method would reveal, according to the latest data of Bouman (1) about four to six times and according to the data of Simpson and Derbyshire (14) about one and one-half times.

The performance of this test does not depend on any peripheral function; the increase of metabolic processes is very slight, no de-

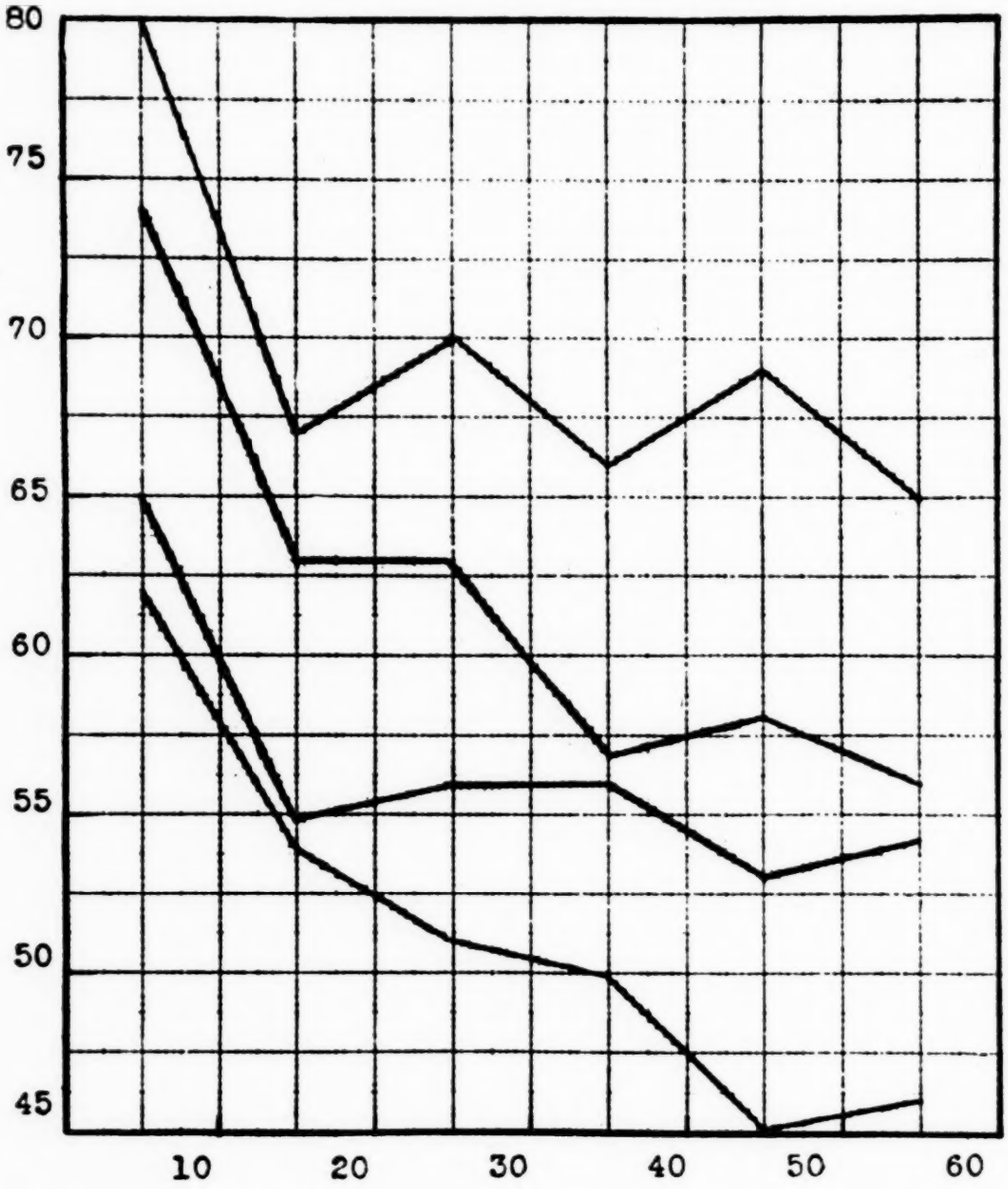

FIG. 1. Drop of motor impulse frequency during the test (Right hand: first performance).

mand for any considerable blood supply is involved nor disagreeable sensations, as for instance characterize static work. The test measures function of the motor centers.

Thornton, Holck and Smith (15) have investigated the effect of Amphetamine by a similar 'tapping test.' In their arrangement two copper plates were mounted one inch apart and separated by a block

raised one-half inch above the surface of the plates. The subjects were required to tap alternately on the plates with a metal stylus. There is obviously a coördination factor involved in this arrangement, the finger movements are performed under visual control. Therefore the results obtained by these authors do not conclusively establish whether the eye-hand association is concerned or the state of the motor centers. In our arrangement no additional coördination factor is involved, so that the results can be related only to the state of motor centers. Furthermore, Thornton, Holck and Smith evaluated the total score made within 30, 120 and 300 seconds. We have found in former investigations that the motor frequency drops rapidly from the first ten seconds, so that the average value even of their shortest period of 30 seconds does not show the maximum value of motor frequency, which is of special physiological importance. The drop of motor frequency during one minute performance indicates the fatigability of motor centers. The drop proceeds more or less regularly, as shows in Fig. 1. We calculated the drop as the difference between the maximum (initial) value and the minimum value during the performance, independent of the time when the minimum occurred.

Method

The subject stood in front of a table, on which a Cenco impulse counter was placed. He had to touch the button of the counter with his middle finger 'as fast as possible.' Before the test the subject was given several trial tests in order to familiarize him with the technique. After that, the subject was asked to begin and to continue 'until the stop signal' which was given after one minute. The number of contacts was registered each ten seconds by means of a stop watch; thus, the values are expressed as the number of motor impulses per ten seconds.

As placebo, an inert preparation was given (sodium bicarbonate). In the control experiments measurements were made in the morning and at the end of the working day. Amphetamine was given at 11:30 A.M. before lunch. Thus, the evening values show the Amphetamine effect. Twenty Amphetamine experiments and twenty control experiments have been made on four subjects. The standard deviation was calculated and the difference of mean values was regarded as significant when it exceeded two times the expression $\sqrt{SD_1^2 + SD_2^2}$. Furthermore, nine control and seven Amphetamine experiments were performed with a group of four laundry workers. As the number of individual values was too small, the mean values, standard deviations, etc. were calculated for the whole group.

Results

Table I shows the results. All mean values are higher on those days when Amphetamine sulfate was applied. This is true for the absolute values in the evening as well as for the difference between morning and evening values. However, this is rather a general tendency, because the differences of most mean values were not significant. The effect was more pronounced in the maximum values than in the minimum values. The only significant changes of the absolute values in the evening were found in the maximum values

TABLE I

EFFECT OF AMPHETAMINE ON THE FREQUENCY OF MOTOR IMPULSES

	Evening Values						Difference: Morning – Evening				Condition	Subj.	Sex	Age	Occupation
	Right Hand			Left Hand			Right Hand		Left Hand						
	Max.	Min.	Drop	Max.	Min.	Drop	Max.	Min.	Max.	Min.					
Mean Value.....	80.0	64.4	−15.6	64.0	53.4	−10.6	+0.40	+0.60	−1.60	+1.20	Control	Mi.	fem.	29	Office work
Mean Value.....	84.0	67.0	−17.0	67.7	54.0	−13.7	+6.33	+6.80	+4.33	+2.30	Amphetamine	Mi.	fem.	29	Office work
Amphet. Effect...	+4.0	+2.6	—	+3.7	+0.6		+5.93	+6.20	+5.93	+1.10		Mi.			
Significant.....	yes	no	—	yes	no		yes	yes	yes	no		Mi.			
Mean Value.....	63.8	53.0	−10.8	57.6	45.0	−12.6	0.0	+0.2	+0.8	−2.2	Control	Sw.	fem.	24	Office work
Mean Value.....	66.2	53.4	12.8	62.4	48.0	−14.4	+3.2	+1.6	+4.0	−0.8	Amphetamine				
Amphet. Effect...	+2.4	+0.4	—	+4.8	+3.0		+3.2	+1.4	+3.2	+1.4					
Significant.....	no	no	—	yes	no		yes	no	no	no					
Mean Value.....	68.0	57.4	−10.6	67.0	53.8	−13.2	−5.0	−3.6	−3.8	−4.2	Control	Ge.	male	33	Laboratory helper
Mean Value	73.8	61.0	−12.8	69.4	58.4	−11.0	+2.8	+1.4	+1.8	+2.0	Amphetamine				
Amphet. Effect...	+5.8	+3.6	—	+2.4	+4.6		+7.8	+5.0	+5.6	+6.2					
Significant.....	yes	no		no	no		yes	yes	yes	yes					
Mean Value.....	62.8	48.6	−14.2	65.8	50.8	−15.0	−1.4	−1.4	+0.5	−1.4	Control	Fr.	male	31	Laboratory helper
Mean Value.....	65.5	51.5	−14.0	70.8	52.8	−18.0	+4.3	+1.3	+7.8	+2.3	Amphetamine				
Amphet. Effect...	+2.7	+2.9	—	+5.0	+2.0	—	+5.7	+2.7	+7.3	+3.7					
Significant.....	no	no	—	no	no		no	no	yes	no					
Mean Value.....	63.0	53.3	−9.7	58.2	44.4	−13.8	−3.6	−2.2	−2.0	0.0	Control	Ho.	fem.	22	Laundry (8 experiments)
Mean Value.....	66.3	56.3	−10.0	59.6	46.8	−12.8	+1.1	+1.1	+1.1	0.0	Amphetamine	Ba.	fem.	29	
Amphet. Effect...	+3.3	+3.0		+1.4	+2.4		+4.5	+3.3	+3.3	0.0		Fo.	male	35	
Significant.....	no	no		no	no		yes	yes	doubtful	no		Ma.	fem.	40	

(subjects Mi., Ge., and Sw.). Consequently, the drop of the motor frequency during the test in the Amphetamine experiments equalled or exceeded that in the control experiments. This would indicate that Amphetamine increases the initial frequency of motor impulses, but it does not influence the fatigability of motor centers.

The mean values of the differences between the morning and evening values show the Amphetamine effect more clearly, because probably the effect of the daily variations is eliminated to a certain extent by this procedure of calculation. There, significant changes were found also in some minimum values, although the changes in the maximum values were greater.

These results confirm those obtained by Thornton, Holck and Smith so far as the general effect of Amphetamine on the motor speed is concerned. The results show that this effect is due more to the initial increase of the maximum speed than to an increase of endurance. At least, the effect of Amphetamine on the maximum frequency is more uniform and consistent than it is on endurance. Thornton et al. investigated the influence of Amphetamine on the fatigability by comparison of the total score made within 30, 120 and 300 seconds. In one of their three subjects the score was better in the 30 second test and worse in the other two. However, their results are not exactly comparable because an association function is involved in their procedure.

The effect of Amphetamine on the fusion frequency of flicker (*i.e.*, on a fundamental sensory function) was more consistent and more pronounced than on the motor centers. In regard to the fusion frequency of flicker, all values on the days without Amphetamine were decreased at the end of the working day, while they were increased after Amphetamine. Table II shows the individual mean values of the fusion frequency of flicker compared to the average initial values of the right and left hand of the same subjects. The difference of the absolute evening values was calculated in percent of the control experiments. The increase of the fusion frequency after Amphetamine in the group of laundry workers is somewhat smaller than that of office and laboratory workers. This is probably due to the fact that in laundary workers the muscular effort is greater and the mental effort less. In any case, the percentage of the increase of motor frequency is less than that of the fusion frequency of flicker. It appears, therefore, that the effect of Amphetamine on the sensory centers (at least the visual centers) is more pronounced than on the motor centers. Yet, the experiments show that Amphetamine may be useful to increase the speed of movements, although the effect on endurance is doubtful. No generalization can be made for other types of speed—work involving greater muscle mass and energy ex-

penditure. The failure to find any consistent influence on the endurance in our test is no contradiction to the increased endurance after Amphetamine in some types of static work, for instance, in the maintained hand grip test (**15**). Endurance in static performance is probably due to inhibition from the sensory centers, while endurance

TABLE II

COMPARISON OF THE AMPHETAMINE EFFECT ON THE FUSION FREQUENCY OF FLICKER WITH THAT ON THE MOTOR FREQUENCY

Subj.	Fusion Frequency of Flicker (Flashes per second) Evening Values			Motor Frequency (Impulses per 10 seconds) Evening Values					
				Maximum Right			Maximum Left		
	Control	Amphetamine	Diff. in %	Control	Amphetamine	Diff. in %	Control	Amphetamine	Diff. in %
Mi.	40.9 (9)	55.2 (6)*	+35.0	80	84	+5.0	64.0	67.7	+5.5
Sw.	45.4 (6)	54.7 (5)	+20.5	63.8	66.2	3.9	57.6	62.4	+8.0
Ge.	39.7 (6)	44.5 (5)	+12.0	68.0	73.8	8.4	67.0	69.4	+3.3
Fr.	45.6 (7)	51.4 (5)	+12.5	62.8	65.5	4.1	65.8	70.8	+7.5
Ba.	37.9 (2)	41.8 (2)	+10.5	67.5	70.0	3.5	58.0	61.0	+5.0
Ho.	39.8 (3)	44.1 (2)	+11.0	59.0	59.5	0.6	56.0	60.0	+7.0
Fo.	40.5 (2)	42.4 (2)	+4.5	61.7	64.5	4.3	62.7	60.5	−3.5
Ma.	38.0 (1)	42.0 (1)	+10.4	70	76	8.5	52.8	57.0	+8.0

* The numbers in parentheses indicate the number of experiments.

in our test is probably due to exhaustion of motor centers. The increased endurance in static performance may well be related to the increase of fusion frequency of flicker.

SUMMARY

Twenty-seven Amphetamine experiments and twenty-nine control experiments were performed on eight subjects. Amphetamine sulfate increased the maximum frequency of motor impulses, while no consistent results in regard to the fatigability of motor centers (endurance) could be obtained.

(Manuscript received May 15, 1941)

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A NOTE ON THE INFLUENCE OF PRAISE AND REPROOF UPON SIZE CONSTANCY

BY RUTH M. CRUIKSHANK[1] AND ELSA FEIGENBAUM[1]

The considerable body of work upon the question of visual size constancy has led to the determination of a number of variables which affect the phenomenon. Thus, while the perceived size of an object located at a distance from the observer approximates the physical size of the object rather than that which might obtain if the retinal image size were the only determining factor, it is known that the perceived size varies with a number of factors.[2] In general, those which give a clue to distance lead to a higher approximation of the physical size. However, there are other factors which seem to be involved, of which the observer's attitude is one. Holaday (4), for example, found that instructions to report the size of an object as it appeared to the observer (synthetic judgment) led to a higher constancy ratio than did instructions to report the size using any psychological means to estimate the size (analytic judgment).

Klimpfinger (5) showed that there is an increase in the constancy ratios for judgments of shape constancy as the observer was given added practice but no knowledge of results, if the judgments were synthetic in character. There was a decrease in the ratios if the observer's attitude was analytical. Henneman's examination (3) of color constancy under 'object-directed' set and 'photographic' set (these corresponding to synthetic and analytic judgments, respectively) likewise showed that there is a lesser degree of constancy for the analytic set. It was possible to change each set under specific instructions and training, but there was some evidence to show greater difficulty in changing from 'object-directed' to 'photographic' attitude. Observers who were not under a particular instruction as to attitude showed no high degree of fluctuation of response.

Problem

The present experiment was undertaken to test whether the observer's performance in judging the size of a distant object as compared with that of a standard near object can be altered through attitudinal changes set up by praise and reproof.[3]

[1] The study was carried out in the Psychological Laboratory of Goucher College.

[2] For other investigations examining this problem and for a discussion of the derivation of size constancy ratios, reference may be made to Brunswik (2), Locke (6, 7) and Sheehan (9).

[3] For a review of some of the work on the effect of praise and reproof on various performances, the reader is referred to Murphy, Murphy, and Newcomb (8) and Blankenship and Humes (1).

Procedure

The stimulus objects used in the present experiment were gray cardboard squares graduated in size by half-centimeter steps from 11 cm to 20 cm. These were exposed in turn for two and one-half seconds at a distance of 200 cm from the observer's eyes and compared with a standard square of 15 cm which was placed at a distance of 150 cm from the observer's eyes. Alternation of the squares from right to left in the visual field was made in random fashion. The stimuli were presented according to the method of limits with a change in size of the object but maintenance of the same distance of presentation. Five ascending and five descending series were given in any one session.

The figures were placed on a table 121 cm wide and 303 cm long, covered with a black cloth. Black cloth also covered that part of the distant field which came within the observer's view. The table was illuminated by two ceiling lights, a 200 watt bulb over the far field and a 75 watt bulb over the near field. These were so placed with reference to the figures that the illumination was approximately the same in both near and far positions.

Chin and forehead rests were used to keep the observer's head at a uniform position. The observer's eyes were 3 cm above the level of the table. A screen prevented the observer from viewing the field between presentations of the stimuli.

The observers were four women college students, three of whom had had previous training in psychological observations. Twelve series of presentations were given each observer over a period of six weeks. In series 1, 2, and 3 the observer was asked to "report whether the farther square *appears* larger or smaller than the nearer one." In series 4, 5, and 6 each observer was presented with a fictitious graph purporting to show results in comparison with a group of college students, and the observer was told that she could see that her own work was very poor in comparison with that of the others and that she should try to do better. Before each of the series 7, 8, and 9 the observer was shown the false graph which was plotted each session to show improved and very satisfactory scores, and the observer was told that her work was excellent. Observers A and C were given series 7, 8, and 9 (praise) before series 4, 5, and 6 (reproof). Series 10, 11, and 12 were presented with no comparison graphs or remarks. The comments were given to all the observers by the junior experimenter in the same fashion but in such a way that they were accepted by the observer. This was evidenced during the interview which the senior author had with the observers after the completion of the experiment. None of the observers was aware of the nature of the problem; none of the observers suspected the falsity of the praise and reproof.

Results

The threshold values for sizes of the variable stimulus figures chosen by each observer to be equal to the constant stimulus figure are given in Table I. Constancy ratios from these values are also included. Inspection of this table will show that even in the first pretest periods there is considerable difference among the observers as to the size of the object chosen as equal to the standard object although the values for an individual observer are relatively uniform. When the praise series is compared with the pretest series, it will be seen that the constancy ratios for two of the observers (A and C) increase, while they decrease for the other two observers (B and D). When the pretest and reproof series are compared, it will be noted that, for all observers except Observer A, there is a lower constancy quotient with reproof. The constancy quotients in the retest series are lower than those for the pretest series in all cases except for Observer A, where the difference is negligible.

TABLE I

THRESHOLD VALUES AND SIZE CONSTANCY RATIOS FOR PRETEST, PRAISE, REPROOF, AND RETEST SERIES FOR FOUR OBSERVERS

Observer	Pretest Series					Praise Series					Reproof Series					Retest Series				
	1	2	3	Average	Ratio	4	5	6	Average	Ratio	7	8	9	Average	Ratio	10	11	12	Average	Ratio
A	15.90	15.95	15.85	15.90	.80	15.95	15.55	15.90	15.80	.82	15.75	16.00	15.60	15.78	.82	15.80	15.85	16.10	15.92	.79
B	15.70	15.45	15.65	15.60	.86	16.15	16.15	16.05	16.12	.75	15.80	15.80	15.90	15.83	.81	16.35	16.15	16.30	16.27	.72
C	15.15	15.25	15.25	15.22	.95	14.90	15.15	15.10	15.05	.99	15.25	15.20	15.50	15.32	.93	15.10	15.35	15.50	15.32	.93
D	17.60	17.65	17.80	17.68	.43	18.00	18.10	18.10	18.07	.35	18.20	18.40	18.25	18.28	.31	18.40	18.55	18.45	18.47	.28

Coincident with the reproof series and, in a few instances, with the praise series was a tendency on the part of the observer to ask to see the figures again or to express doubt about the judgments. Observer A, however, whose judgments, it will be noted, remained approximately the same throughout the series, asked for re-exposure only during the first day's trials. According to the other observers' remarks, reproof was particularly upsetting. The final retest trials, while they were not accompanied by praise or reproof, were generally carried out with an attempt on the part of the observer to do better.

Summary

The results of the present study suggest that under the praise-reproof situation of the experiment size constancy judgments tend to change in such a way that finally the observer chooses a somewhat larger figure which is reported as appearing equal to a standard square than was done initially. In other words, in endeavoring to 'better' the results, the observer chooses a figure which is less like the physical size of the standard square. These results are similar to those which Holaday (**4**), Klimpfinger (**5**) and Henneman (**3**) found for the analytic (subjective, 'photographic') instructions which they gave.

The limited results obtained here cannot answer the question whether either praise or reproof given alone over a period of time will lead to the same trend in the constancy quotient or whether there might be some evidence of the upward trend like that of the synthetic attitude if praise alone were given.

The experiment points out again the presence of individual differences and the effect of attitude upon size constancy judgments.

(Manuscript received May 15, 1941)

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Vol. 29, No. 6
DEC 5 1941
December, 1941

Journal of Experimental Psychology

EDITED BY

SAMUEL W. FERNBERGER
UNIVERSITY OF PENNSYLVANIA

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PUBLISHED MONTHLY, TWO VOLUMES PER YEAR
BY THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.
PRINCE AND LEMON STS., LANCASTER, PA.
AND NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

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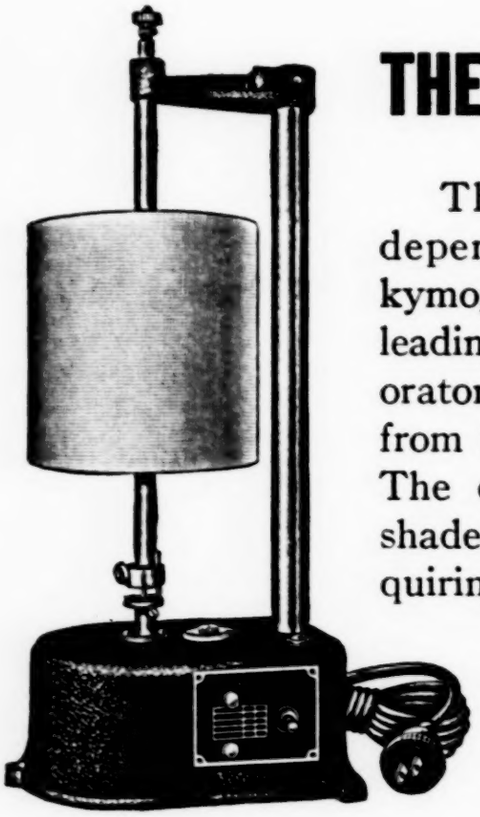

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